SEISMIC SAFETY PLAN

AN ELEMENT OF THE GENERAL PLAN, SANTA CLARA COUNTY

SEISMIC SAFETY PLAN

An Element of the General Plan

Santa Clara County

Adopted as an Element of the General Plan of Santa Clara County by the County of Santa Clara Board of Supervisors on January 12, 1976

County planning Santa Clara co.
Emerg. relief Earthquakes

Published by the County of Santa Clara Planning Department
70 West Hedding Street, San Jose, California 95110

TABLE OF CONTENTS

Page

List of Figures iii

Introduction 1

Recommendations for the Seismic Element 5

Existing Land Use and Its Relationship to Hazards 9

Earthquake Related Fire 9

Earthquake Related Flooding 11

Disaster Planning 12

Geologic Setting (Prepared by the California Division of Mines and Geology 19

Seismic Hazards and Land Use 19

Geotechnical Site Investigations 19

Earthquake History 24

Potential Earthquake Hazards 30

Non-Seismic Conditions 46

Subsidence 46

Expansive Clays 46

Peat and Other Organic Soils 46

Bay Mud or Soft Clay 47

Soil and Geologic Effects on Building Damage During Earthquakes (Prepared by H. Bolton Seed, Ph.D.) 51

Soil Instability 51

Effects of Local Soil Conditions on Damage Due to Shaking 52

Seismicity and Structural Design 59

Structure Types 59

Foundations 62

Design 63

Local Conditions 65

Page

Balancing Risks 67

Relationship to Other Elements of the General Plan 70

Public and Quasi-Public Facilities and Community Services 73

Public Utilities 75

Circulation 85

Hospitals 89

Public Buildings 92

Schools 92

Urban Development/Open Space 92

Glossary 99

Appendices A-I 107

Appendix J 119

LIST OF FIGURES

		Page
Figure One:	Santa Clara County Geologic Investigations Index	3
Figure Two:	Possible Inundation	13
Figure Three:	Areas Potentially Isolatable in Seismic Emergency	17
Figure Four:	Seismic Safety Zones	21
Figure Five:	Slope and Seismicity Characteristics	25
Figure Six:	Earthquake History of Monte Bello Ridge	27
Figure Seven:	Earthquake History of South County	28
Figure Eight:	Types of Fault Displacement	36
Figure Nine:	Former Marshlands	49
Figure Ten:	Potential Hazards Due to Soil Liquefaction	53
Figure Eleven:	Variation of Soil/Structure Interactive Factor	57
Figure Twelve:	Acceleration Response Spectra	58
Figure Thirteen:	Earthquake Insurance Classification	60
Figure Fourteen:	Scale of Acceptable Risks	68
Figure Fifteen:	Lifeline Regulation and Earthquake Concerns	71
Figure Sixteen:	Lifeline Regulations and Earthquake Concerns (Continued)	72
Figure Seventeen:	Major Water Conduits	77
Figure Eighteen:	Sanitation Facilities	81
Figure Nineteen:	Major Gas and Electric Lines	83

Page

Figure Twenty: Circulation 87

Figure Twenty-One: Public and Quasi-Public Structures 93

Figure Twenty-Two: Urban Development 95

Reproducible Maps Available at the Transportation Agency

Plate 1: Geologic Map (Scale 1" = 1 mile)

Plate 2: Seismicity Map (Scale 1" = 1 mile)

Plate 3: Subsurface Data Map--Depth to first ground water

Plate 4: Subsurface Data Map--Thickness of alluvium

Plate 5: Subsurface Data Map--Engineering boring data

Plate 6: Relative Seismic Stability Map

INTRODUCTION

The objectives of the State mandated Seismic Element are very clearly stated:

1) to reduce loss of life, injuries

2) to minimize damage to property

3) to prevent economic and social dislocation.

How to reach those objectives is the task of local government. The quality of Seismic Elements adopted throughout the State will vary depending on the interest and expertise available to develop the background information and recommended actions. Santa Clara County is fortunate in that there has been local interest in earthquake hazards over a period of several years. The cooperative U. S. Department of Agriculture Soils Report started in 1966 was one of the first soils reports in the nation to include information on engineering properties of soils rather than the traditional information relating to agricultural characteristics exclusively. The same year the County had two special reports prepared on geology locating the extent and depth of young bay mud and an aerial photographic analysis of landslides in the hillsides. At that time Flood Control was part of the County family and that department hired its first engineering geologist in 1966.

Following that start, there has been a series of cooperative contracts with the California Division of Mines and Geology (CDMG) to do an interpretive geologic analysis of each selected area in the County (figure 1). While there is interest in examining the entire County in detail, the resources, both financial and professional expertise, are limited, so priorities have had to be established. To date the contracts with the CDMG have dealt with the Santa Cruz Mountains, Monte Bello Ridge, South County, and Seismic Element. The Baylands Geologic and Structural Engineering Report was prepared by private consultants: Woodward, Lundgren & Assoc. (geology and soils) and McClure & Messinger (structural engineers). That report developed risk zones with recommended land uses. The Seismic Element was prepared by a team consisting of: County Planning (planning), County Transportation Agency (geology), CDMG (geology and seismology), and Dr. H. B. Seed (soils engineer). We have attempted to integrate the disciplines of planning, geology, and engineering in the Seismic Element.

Throughout this report the San Fernando earthquake of 1971 with a magnitude of 6.6 on the Richter scale is mentioned frequently. The reasons that this particular earthquake is of such significance to Santa Clara County are:

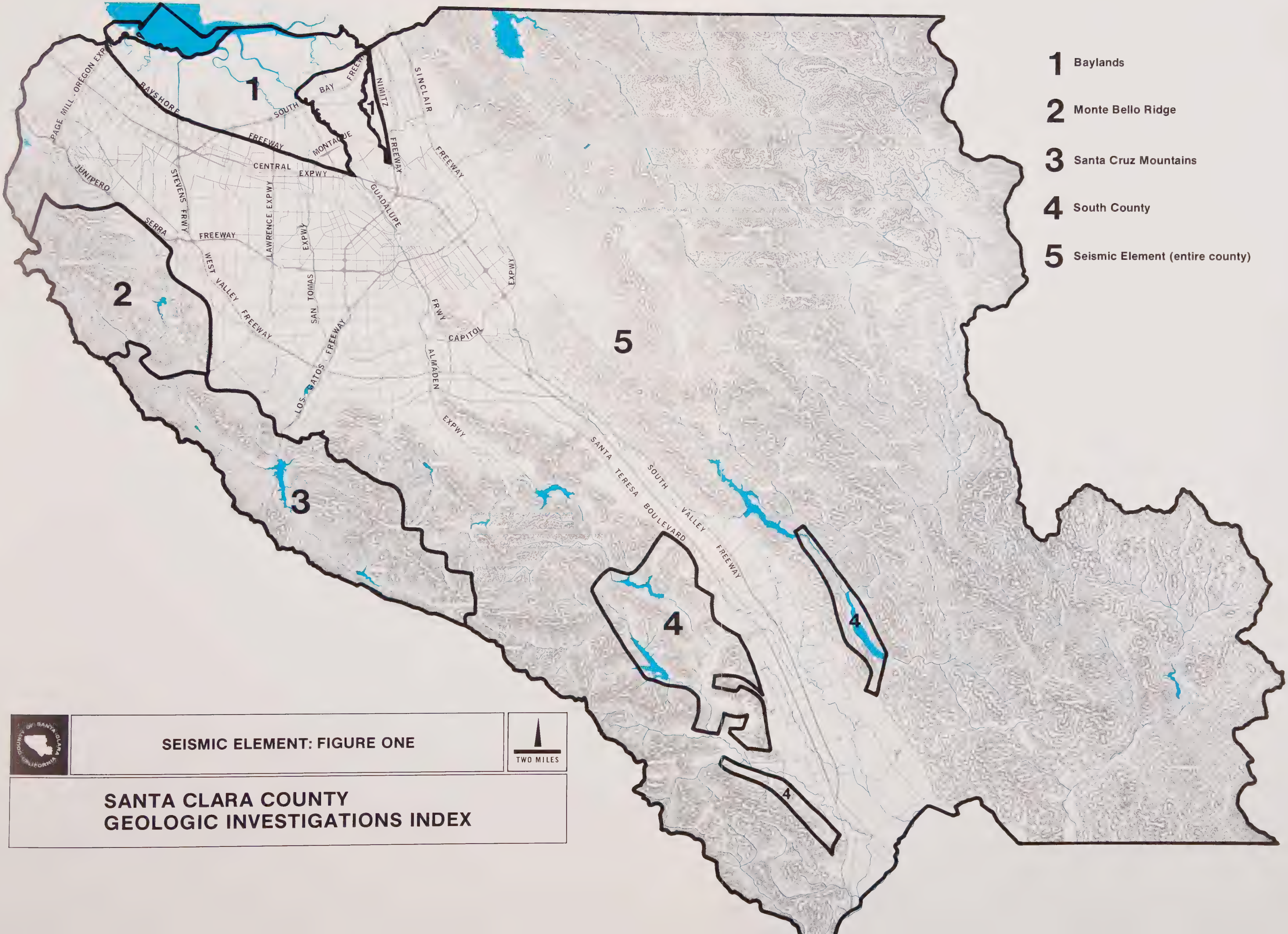
1. It has been the most thoroughly investigated so there is a great deal of information available using the most recently developed analysis techniques;

2. Most of the structures were built under modern building codes so that the adequacy of those codes can be evaluated, particularly for California; and

3. The vulnerability of public and quasi-public facilities such as gas, electricity, sewer lines, water, telephone, and freeway structures was made apparent with the same standards of construction normally used by those agencies in Santa Clara County in 1971.

A workable Seismic Element must include considerations which are sensitive to many aspects of the physical and political environment of an area. This paper presents information on existing land use and how it may be affected by seismic hazards, a comprehensive account of the geologic conditions of the County, analyses of soil instability and its effect on buildings, either with or without seismic upheaval, recommendations for structural designs that best withstand seismic shock, and most importantly, recommendations for minimizing the risks of earthquake damage in the context of the present economic and societal conditions.

It is as a result of the lessons learned in the San Fernando and other earthquakes that the Seismic Element has been prepared. The public should expect and receive reports that can be implemented in the real world. This report was written with that intent.



SEISMIC ELEMENT: FIGURE ONE

SANTA CLARA COUNTY
GEOLOGIC INVESTIGATIONS INDEX

RECOMMENDATIONS OF THE SEISMIC ELEMENT

Two major recommendations to be expected in a Seismic Element have already been effected in the County. They are listed here as an aid to the city jurisdictions using this Element as a guide or supplement to their own Seismic Elements:

1. Public agencies responsible for evaluating proposed development should augment their staff by retaining the services of an engineering geologist registered by the State of California either as staff or on a consultant/retainer basis.

2. Appropriate ordinances should be adopted to enforce on-site geologic investigation requirements prior to construction in areas subject to geologic hazards.

URBAN DEVELOPMENT/OPEN SPACE RECOMMENDATIONS:

1. Where urban development has already occurred and there has been a heavy capital improvement with urban services available, mitigation procedures should be used for urban development:

    a. A geologic investigation should be conducted on a scale commensurate with development where geologic data indicates there is a known or suspected problem.
    b. Site preparation should be directed at long term geologic stability as well as other environmental enhancement.
    c. Critical structures should be designed and constructed above and beyond Uniform Building Code where such measures are deemed necessary from available geologic and engineering data. Critical structures are those structures (1) needed after a disaster: emergency communications, fire stations, hospitals, bridges, and overpasses; (2) whose continued functioning is critical: major power lines and stations, water lines, and other utilities; and (3) whose failure might be catastrophic: large dams.
    d. Each jurisdiction should develop a long range inspection program for hazardous structures. Priorities for the inspection program should be based on critical nature of structure after a disaster and levels of occupancy (high vs. low and involuntary vs. voluntary).

2. Where urban development has not yet occurred such as the hillside and parts of the baylands that have geologic constraints associated with environmental factors such as steep slopes, flooding, fragile or scarce wildlife and vegetation, and little or no urban services and facilities, the major land uses should be largely open space uses.

3. Urbanization of hazardous areas should be discouraged by public agencies such as the Local Agency Formation Commission (which deals with annexations and formation of special districts) and planning commissions (for general planning and zone changes).

PUBLIC AND QUASI-PUBLIC FACILITIES AND COMMUNITY SERVICES RECOMMENDATIONS:

1. All agencies responsible for operating "lifelines" in Santa Clara County should: a) make an evaluation of the seismic resistance of their existing and proposed facilities including access to facilities in order to repair damage, b) report the results of that evaluation to affected jurisdictions, and c) describe how they plan to improve the conditions. The evaluation should deal with the entire County as well as each potentially isolatable area.

2. All agencies responsible for operating "lifelines" in Santa Clara County should encourage the upgrading of the professional level of education related to earthquake engineering by education of present staff and hiring or having on retainer the necessary expertise to evaluate and solve seismic problems as related to their agency functions.

3. Establish a Santa Clara County "clearing house" for lifeline information, evaluation, and plans in order to help set priorities to resolve existing local earthquake hazards.

4. Duplicate records (perhaps on microfilm) of utility systems and other lifeline components should be stored in emergency operations centers for continuing operations and repair of vital services in the event of a disaster.

5. Emergency operations center structures should be evaluated for seismic vulnerability and should be designed and constructed to assure the continuity of vital services following a damaging earthquake.

6. Locational studies for future hospital, outpatient, and emergency medical facilities should weigh the needs within each potentially seismically isolatable area.

7. Each household should make providions for storing at least three-and-one-half gallons of drinking water for each family member.

8. Each potentially isolatable geographic area should develop a self-contained water supply by storage facilities, dry wells, percolation ponds, effluent reclamation, and/or other feasible means.

CIRCULATION RECOMMENDATIONS:

1. Existing transportation routes, facilities, and structures should be evaluated for vulnerability.

2. Proposed transportation routes, facilities, and structures should be evaluated for potential vulnerability and built only if problems can be sufficiently mitigated.

3. Highway bridges (overpasses), where seismic safety is questionable, should receive high priority for repair or replacement.

SEISMICITY AND STRUCTURAL DESIGN RECOMMENDATIONS:

1. A long range hazardous building inspection program should be planned with the critical structures given high priority.

2. Critical structures should be designed to resist minor earthquakes without damage; resist moderate earthquakes without structural damage, but with some nonstructural damage; and resist major earthquakes of the intensity or severity of the strongest experienced in California without collapse, but with some structural as well as nonstructural damage.

3. Critical structures should be designed using the "Recommended Lateral Force Requirements" prepared by the Structural Engineers Association of California.

4. Residents of low/moderate income and substandard housing suspected of being unsafe should receive high priority for subsidized housing.

GEOLOGIC RECOMMENDATIONS:

1. Development along the low-lying bay margin should be discouraged to prevent possible flooding damage from the risk of levee failure. Because flooding may extend from 5 to 10 feet above sea level (depending on combinations of actual conditions), the landward limit of any restricted area may be chosen at any elevation between 5 and 10 feet to match various risk levels.

2. The dikes protecting the low areas, some of which are below sea level, must be kept in good repair and should be improved. Such improvements should be consistent both with the recommendations of Tudor Engineering (1973) and with the policies in "A Policy Plan for the Baylands of Santa Clara County" (Santa Clara County Planning Department, 1972)--which recommends improvement of only the inboard (landward) dike system.

3. Regarding shoreline development around reservoirs and lakes in the County, damage from possible seiche and landslide splash waves should be considered on a site-by-site basis. The seiche hazard should be particularly considered at Coyote Reservoir, and the landslide splash hazard should be particularly considered at Stevens Creek, Lexington, Lake Ranch, Howell, Anderson, Coyote, and Pacheco Reservoirs.

4. A periodic updating of geologic, seismic, and engineering data should occur in recognition of state-of-the-art advances.

RISK EVALUATION AND DISCLOSURE RECOMMENDATIONS:

1. Known or potential geologic, fire, and flood hazards should be reported as part of every real estate transaction, as well as recordation on documents to be reported for building permits, parcels, subdivisions, and land development reports. Mitigation of hazards should be noted in the same manner.

2. Private and public agencies involved in land development such as lending agencies, title companies, real estate brokers, appraisers, engineers, and contractors should be provided with hazard data as soon as it becomes available.

3. A post-earthquake land use contingency plan should be developed and made available to all federal, State, and local agencies normally involved in post-disaster rehabilitation.

DISASTER PLANNING(SHORT AND LONG TERM) RECOMMENDATIONS:

1. Public information on earthquake hazards and disaster planning should continue and be improved to stress natural disasters as well as nuclear holocaust.

2. Support public information programs dealing with minimizing the impact of natural hazards ranging in scope from family preparedness to long range land use planning and land development regulations.

EARTHQUAKE RELATED FIRE RECOMMENDATIONS:

1. Intensify fire prevention education program in both rural and urban areas.

2. Establish a long range inspection program for fire prevention with highest priority established by the nature of occupancy (schools, hospitals, jails, and nursing homes) and level of occupancy (high density use--hotels, apartments, offices, theaters, churches).

EARTHQUAKE RELATED FLOODING RECOMMENDATIONS:

1. Construction of the strengthened inboard (landward) levee in the Baylands should begin at the earliest possible date.

2. Until the strengthened salt water levee is constructed urban development should be prohibited in the "drylands" area unless the structures are placed on pads elevated above the level of expected flooding (salt water and 1% flood). Land use of the "water areas" of the Baylands should follow PPC Baylands Policy Plan recommendations.

3. More definitive data on damaging waters (that which from dam inundation would be a threat to life and major property damage) should be developed at the earliest possible date.

4. Until the area of damaging waters from dam failure inundation is identified, areas immediately below dams should be restricted from development and given high priority for open space acquisition.

5. Designated floodways should be identified at the earliest possible date.

6. Flood plain zoning or riparian zoning should be applied to designated floodways in order to maximize life safety, reduce property loss, and preserve natural vegetation, wildlife, and scenic beauty.

EXISTING LAND USE AND ITS RELATIONSHIP TO HAZARDS

The land use element of the general plan defines the appropriate use of land and the relationship of those uses to one another. In the past, criteria for land use recommendations in Santa Clara County, with few exceptions, have not included seismic factors. As an example, our downtown areas developed largely as a result of historic settlement patterns and later as a function of community focus. To pass existing and proposed land uses and structural types through the seismic sieve is to evaluate them from a totally different perspective. When the revised land use element of the general plan is developed, seismic hazards will be weighed along with several other considerations such as environmental sensitivity, flood hazards, existing public facilities and services, and economic considerations, both public and private.

EARTHQUAKE RELATED FIRE

While most of the existing structures and types of occupancy are not serious problems, there are sections of old downtown areas that have structures of questionable earthquake stability and are more susceptible to fire hazard because of close proximity to each other. Fire following an earthquake can cause greater loss of life and property than the earthquake itself. Eighty percent of the property loss in San Francisco (1906) was attributed to fire which spread not only because of the inadequacy of the water supply but also because of the proximity of combustible material as compared to small fires in the San Fernando earthquake of 1971 which were more dispersed in a typical suburban residential density. The highest residential fire hazard is generally found in older structures, mobile homes, condominiums without one-hour fire walls, and old hotels. In the past, the density of land use was the highest in the old downtown area with decreasing density as the distance increases away from the urban centers. More recently, major thoroughfares, this historic density pattern has changed. The intensity of land use in the low lying baylands area and hillsides remains low compared to the valley floor. There is, however, increasingly greater pressure for development in the hills as some people choose to move from an urban or traditional suburban setting.

The time of year, such as the end of the dry season, and weather conditions, such as high winds, will also affect the probability and extent of fire hazards. Hillside locations are particularly influenced by seasonal conditions. Hillside fires that might coincide with a seismic disaster would be most hazardous to life safety where access is limited to dead end roads and any roads susceptible to closure due to landslide or washout.

Numerous fires on the valley floor following a seismic disaster would test mutual aid expectation since most fire agencies would be preoccupied with local fires and might also find it difficult to reach some areas that might be isolated by bridge and freeway overpass collapse, or building debris on the roadways.

The other categorical fire hazard relates to the storage of flammable liquids and fuel pipelines. This topic is discussed under "Utilities."

EARTHQUAKE RELATED FIRE RECOMMENDATIONS

1. Intensify fire prevention education program in both rural and urban areas.

2. Establish a long range inspection program for fire prevention with highest priority established by the nature of occupancy (schools, hospitals, jails, and nursing homes) and level of occupancy (high density use--hotels, apartments, offices, theaters, churches).

EARTHQUAKE RELATED FLOODING

The threat of flood is related to the seasons, tide stage, and amount and duration of rainfall. There is also a dependency on the seismic stability of man-made structures, such as levees, dams, tunnels, flood control channels, and storm drains. There are three major categories of potential flooding in Santa Clara County: the 1% or 100 year flood, salt water flooding in the Baylands, and inundation due to dam failure.

If all the existing flood control facilities remained intact and a 100 year (or 1%) flood were to occur, a substantial part of the valley floor would be inundated by fresh water. Substantial damage occurred to open storm drain channels and tunnels in the San Fernando earthquake.

Previous reports from the Water District have mapped the areas of salt water flooding in the Baylands area if the levee system were to fail (figure 2). Some sections of levees are expected to fail with a 5.7 magnitude earthquake on the Richter scale. The Planning Policy Committee's Baylands Plan found that the flood hazard was the most severe risk in that area. In order to protect already developed areas in the Baylands, a choice must be made on how to protect that property. The PPC Baylands Plan recommended strengthening the inboard (landward) levees rather than the outboard (bayward of salt ponds) levees.

The third kind of flood problem would result from dam failure. Dams as well as levees may be considered as critical structures whose failure would cause a significant number of injuries and perhaps loss of life.

Dams in the County are judged safe by the California Division of Safety of Dams. However, among the recommendations of the Joint Committee on Seismic Safety to the State Legislature is found--"A permanent State Board should be established, having a continuing responsibility for: (1) advising the Division of Safety of Dams on the adequacy of standards of safety for structures under its jurisdictions; (2) determining whether the division is adequately staffed to fulfill its responsibilities for public safety; (3) checking that the necessary standards of safety are adequately enforced; and (4) advising on technical problems related to the safety of dams in California."

The Santa Clara Valley Water District and other dam owners have prepared maps of areas which would be subject to inundation if dams were to fail with the reservoir level at its highest. The preparation of these maps was initiated after State legislation mandated it. We do not have a clear idea from the available data how much of the projected inundation area delineates damaging waters, a threat to life safety and a cause of major property damage. Since the available data shows such an enormous expanse of land, there is a reluctance to restrict development without more definitive analysis. If inundation areas were mapped, which would reflect damaging waters from reservoirs at their average capacity, then the implementation of protective measures might become feasible by acquisition for park and open space uses over a smaller area or special design for structures to withstand damaging waters. As an example, Anderson Reservoir is at 50% capacity 80% of the year. Critical emergency facilities might also be better evaluated with such mapping. The California Division of Safety of Dams is requiring the Santa Clara Valley Water District to prepare an earthquake safety study on each of its eight dams with the following priority: Stevens Creek, Calero, Almaden, Guadalupe, Lexington,

Vasona, Anderson, and Coyote. Uvas and Chesbro Reservoirs belong to the South Santa Clara Valley Water Conservation District; these dams are also being studies.

EARTHQUAKE RELATED FLOODING RECOMMENDATIONS

1. Construction of the strengthened inboard (landward) levee in the Baylands should begin at the earliest possible date.

2. Until the strengthened salt water levee is constructed urban development should be prohibited in the "drylands" area unless the structures are placed on pads elevated above the level of expected flooding (salt water and 1% flood). Land use of the "water areas" of the Baylands should follow PPC Baylands Policy Plan recommendations.

3. More definitive data on damaging waters (that which from dam inundation would be a threat to life and major property damage) should be developed at the earliest possible date.

4. Until the area of damaging waters from dam failure inundation is identified, areas immediately below dams should be restricted from development and given high priority for open space acquisition.

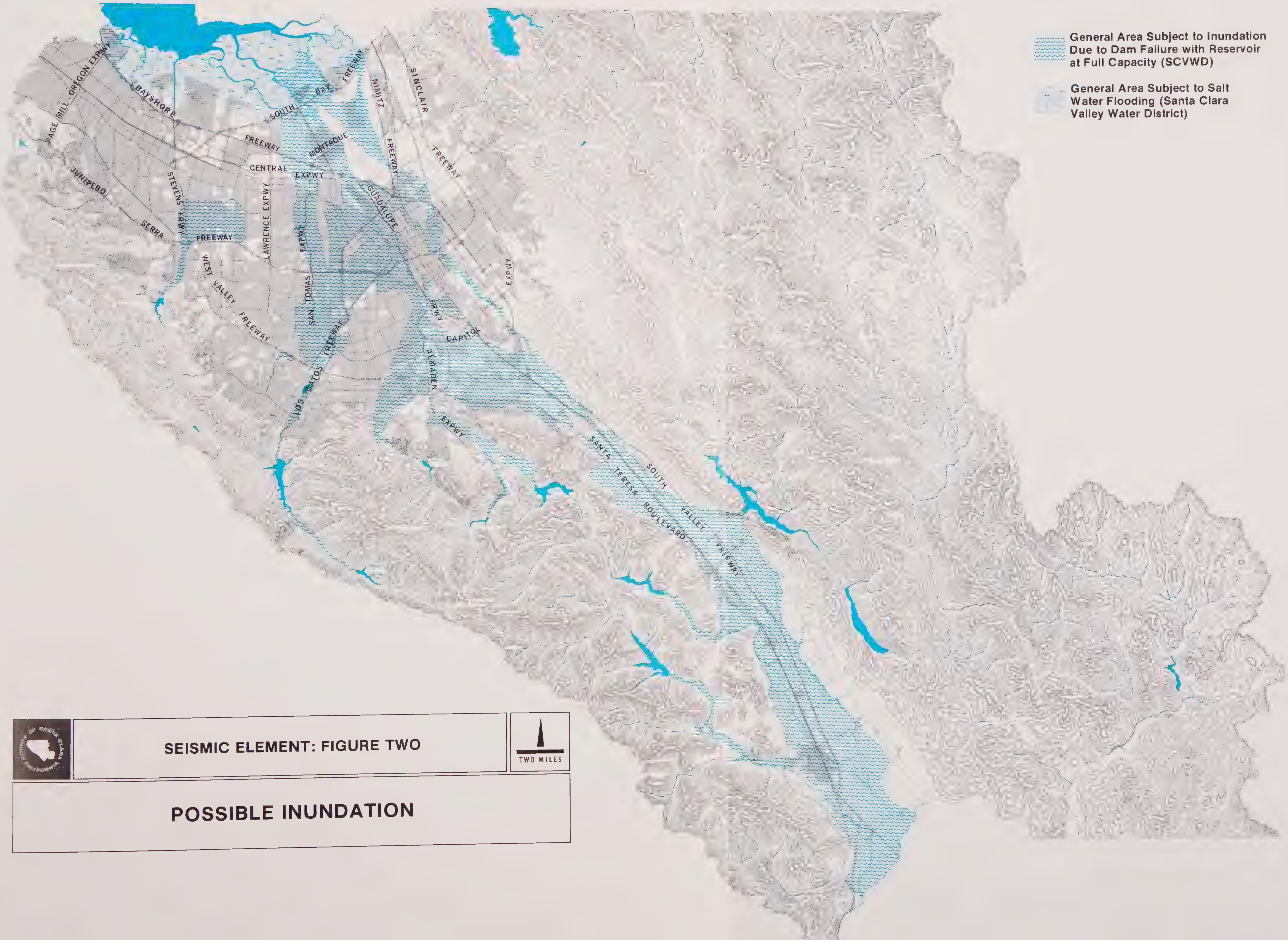
5. Designated floodways should be identified at the earliest possible date.

6. Flood plain zoning or riparian zoning should be applied to designated floodways in order to maximize life safety, reduce property loss, and preserve natural vegetation, wildlife, and scenic beauty.

DISASTER PLANNING

If a large earthquake were to occur at 2:30 a.m. the greatest proportion of the population would be at home in bed; at 2:00 p.m. most people would be away from home at work or school or on business; and from 4:30 to 6:30 the commute traffic would be on the road.

There are three entirely different scenarios for each of these time frames. The first would focus on the condition of residential structures and their locations, the second, on the working scene--offices, commercial and industrial structures, and the third on freeways, overpasses, bridges, and roadways. The San Fernando earthquake occurred early in the morning when most people were at home. The Alaskan earthquake occurred on Good Friday when school was not in session. The behavior of different structural types under earthquake stresses in various geologic conditions will be discussed later in the report. The "middle-of-the-day" earthquake which would catch most people away from home could cause the most confusion since the normal human reaction to such an event is to find out as quickly as possible about the safety and welfare of family, relatives, and friends. This kind of reaction clogs lines of communication and roadways often to the detriment of legitimate rescue efforts of fire, police, and other people trained in emergency service response.



SEISMIC ELEMENT: FIGURE TWO

POSSIBLE INUNDATION

Most individuals and families have not made emergency plans for where they will go (or stay as the case may be), what they will do there, or for storage of water, emergency supplies, and food. There is normally very little cost involved in assembling such supplies. The public apathy toward emergency preparedness on a household basis may be due to several factors; their lack of information on what to do, reluctance to acknowledge the probability that a catastrophic earthquake will occur in their lifetime in Santa Clara County, reluctance to spend the small amount of time necessary to plan emergency actions and assemble emergency supplies, and belief that rescue aid will arrive almost immediately.

Emergency service training exercises, held at least once a year, acknowledge that in the event of an earthquake of a large magnitude, only the highest priority emergencies would be dealt with in the first 24-36 hours. This means that most households will have to cope with their own situation during that time period. The idea that one can get into one's car and seek aid may not be plausible. Roads and freeways are discussed later in the report under "Circulation."

If, for planning purposes, it is assumed that the freeways are not usable and the overpasses are not open, we begin to view the County from the perspective of isolatable units. Figure 3 shows the estimated day/night population for potentially isolatable units bounded by creeks, freeways, overpasses, and some bridges. To give a sense of priority to the number of people who might be isolated, the reader should keep the isolatable units in mind as the report is read, particularly for their self-sufficiency for emergency services, utility, and service vulnerability.

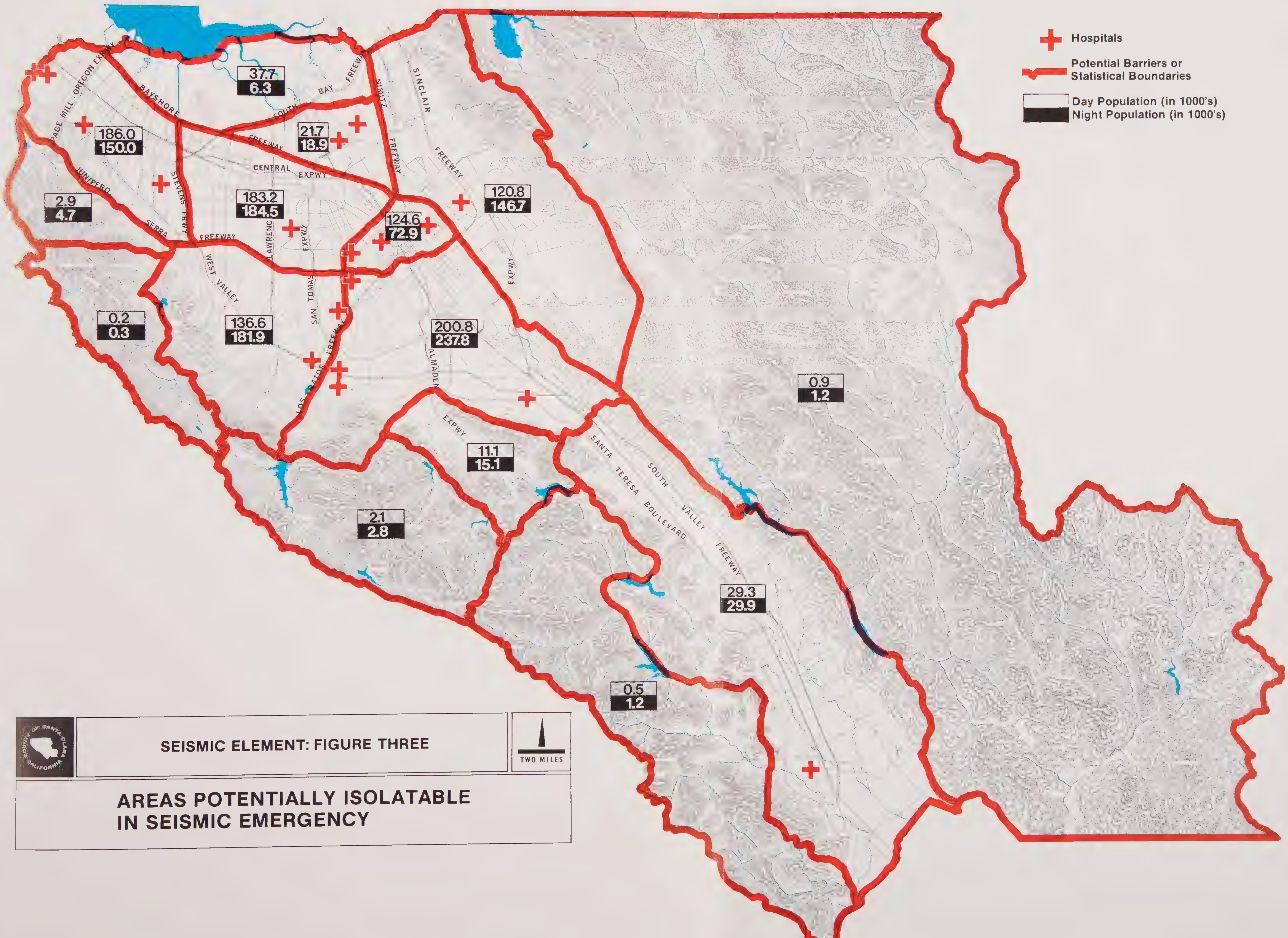
Most emergency plans in California assume large scale disaster, such as a major Bay Area earthquake. Mutual aid may not be available from outside agencies in the first 24 to 48 hours. Political jurisdiction as well as families and individuals should prepare for self-help during the early stages of a major disaster or emergency. If each household set aside food, water, and emergency supplies for a 2-3 day period, it would be a minimal cost to the government to distribute an emergency preparedness booklet such as In Time of Emergency.

This discussion of land use, earthquake hazards, and disaster planning has explained some facets of the problem in Santa Clara County, with an eye to what precautions must be taken by the public. The article following, by the California Division of Mines and Geology, gives detailed information about the geologic hazards in the County, and recommends courses for dealing with these potentially hazardous conditions.

DISASTER PLANNING (SHORT AND LONG TERM) RECOMMENDATIONS

1. Public information on earthquake hazards and disaster planning should continue and be improved to stress natural disasters rather than nuclear holocaust.

2. Support public information programs dealing with minimizing the impact of natural hazards ranging in scope from family preparedness to long range land use planning and land development regulations.



SEISMIC ELEMENT: FIGURE THREE

AREAS POTENTIALLY ISOLATABLE IN SEISMIC EMERGENCY

SEISMIC HAZARDS AND LAND USE

The severity of seismic hazards varies widely as shown in figure 4. It is recommended that specific land uses take these relative hazards into account by the assignment of low-density land uses to high-hazard areas and high-density uses to low-hazard areas.

For example, it is strongly recommended that no structure for involuntary human occupancy be allowed in active fault zones as defined by the Alquist-Priolo Geologic Hazard Zones Act. Such structures include schools, hospitals, and correctional facilities.

Because of the possibility of damage resulting from water movements generated by earthquakes, the following recommendations are made:

Geologic Recommendations

1. Development along the low-lying bay margin should be discouraged to prevent possible flooding damage. Because flooding may extend from 5 to 10 feet above sea level (depending on combinations of actual conditions), the landward limit of any restricted area may be chosen at any elevation between 5 and 10 feet to match various risk levels.

2. The dikes protecting the low areas, some of which are below sea level, must be kept in good repair and should be improved. Such improvements should be consistent both with the recommendations of Tudor Engineering (1973) and with the policies in "A Policy Plan for the Baylands of Santa Clara County" (Santa Clara County Planning Department, 1972)--which recommends improvement of only the inboard (landward) dike system.

3. Regarding shoreline development around reservoirs and lakes in the county, damage from possible seiche and landslide splash waves should be considered on a site-by-site basis. The seiche hazard should be particularly considered at Coyote Reservoir, and the landslide splash hazard should be particularly considered at Stevens Creek, Lexington, Lake Ranch, Howell, Anderson, Coyote, and Pacheco Reservoirs.

4. A periodic updating of geologic, seismic, and engineering data should occur in recognition of state-of-the-art advances.

GEOTECHNICAL SITE INVESTIGATIONS

In order to maximize public safety and minimize seismic hazards, additional local geotechnical studies should be performed prior to further development in many areas of the County (see plate 6).* These studies should consider the data in this report as general background and regional material and should determine the extent of particular seismic hazards on each site in relation to the specific intended use.

These geotechnical investigations should be multidisciplinary, including component studies of seismology, engineering geology, planning, hydrology, archi-

---

*References to "plates" refer to large maps on file at the County Transportation Agency. Prints are available for a small charge. Titles of plates are listed in the index.

tecture, design engineering, structural engineering, and soil engineering. These interrelated components should be coordinated so that all pertinent factors are considered.

To review and approve these geotechnical investigations, it is recommended that the County should develop an adequately trained and funded staff team including the various disciplines mentioned above. Many of these disciplines are represented in various County departments (e.g., geology, engineering, planning). Consultants could be used on an "as needed" basis to supplement existing expertise. Existing committees may contribute to the needed expertise (e.g. Land Development Committee or Architectural and Site Approval Committee).

A similar recommendation in the Baylands Planning Study was adopted in July 1972 by the Planning Policy Committee of Santa Clara County. This recommendation proposed establishment of procedures for geotechnical site investigations in the baylands and review of these investigations by an "Advisory Board." Perhaps the scope of this proposed Advisory Board, patterned after the experience of the San Francisco Bay Conservation and Development Commission (Cluff and McClure, 1970, Part 2, p. 54-57), could be expanded to include the entire county. Separate committees of the Board could deal with special problems of the various terrain units--bayland, Santa Clara Valley, and hillside-intermontane valley areas.

UPDATING DATA AND STATE-OF-THE-ART

These recommendations are based upon currently available data and state-of-the-art. The many disciplines involved in earthquake studies are becoming more knowledgeable as additional studies produce new geologic, seismic, and engineering data. In order to maximize the usefulness of this report, in the future, periodic updating of data and recognition of state-of-the-art advances should occur.

A multidisciplinary committee should be established to accomplish this periodic geotechnical update. Perhaps an existing group, such as the Land Development Committee or Architectural and Site Approval Committee, could serve as a nucleus. Disciplines represented on this committee should include, at least, design engineering, geology, soil engineering, structural engineering, and planning.

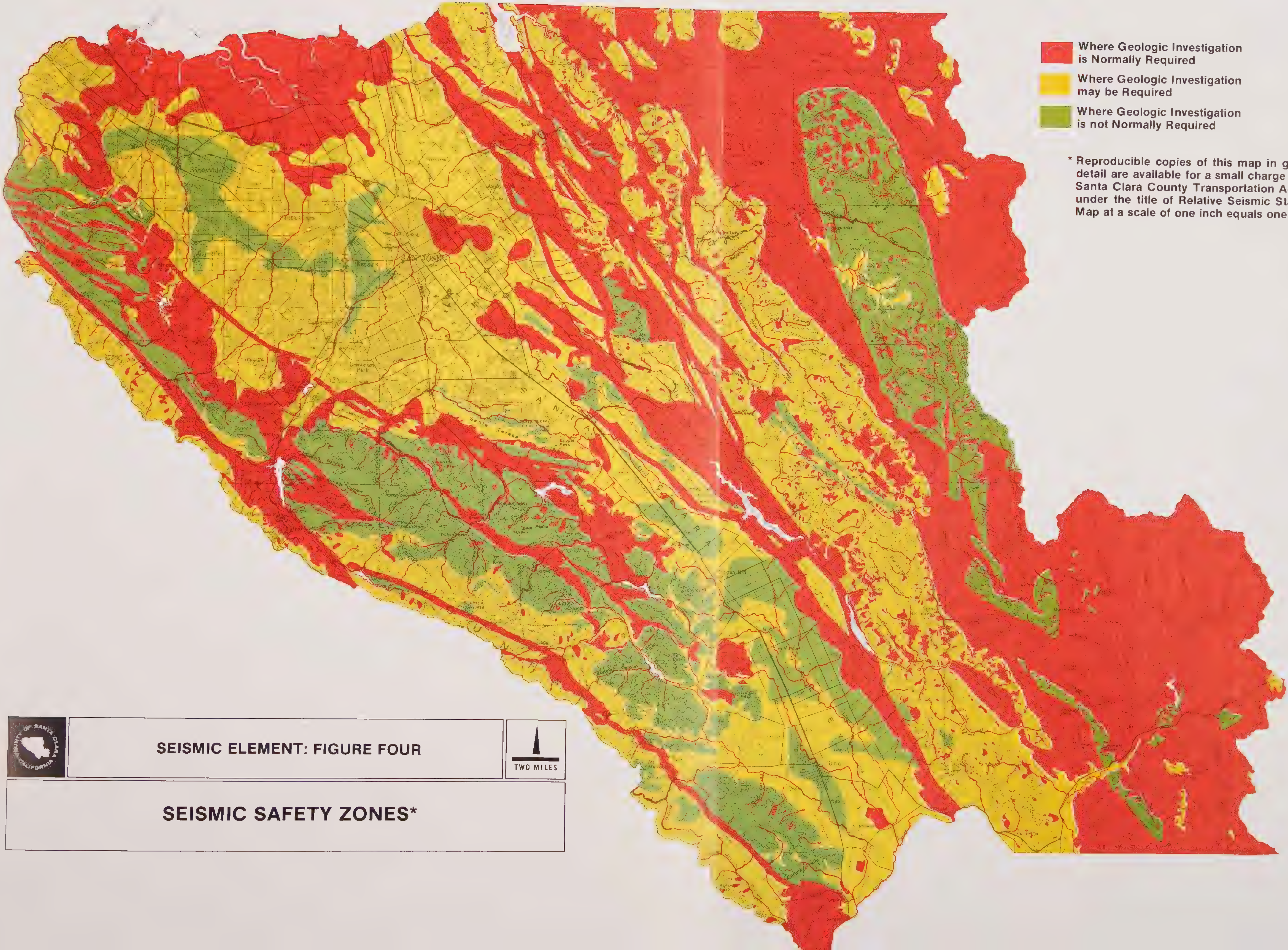
This formal updating program should include a computerized geotechnical data bank. Between periodic updates, an active inventory of pertinent geotechnical data should be maintained. Data sources should include active City and County files, Federal and State agency studies, and available private consultant site studies.

Types of geotechnical data gathered for the data bank should include:

1. earthquake seismology information: earthquake location, earthquake prediction, and source mechanism studies (typical data sources: USGS*, UCB);

---

*CDMG=California Division of Mines and Geology. CDT=California Department of Transportation. CDWR=California Department of Water Resources. CIT=California Institute of Technology. EERI=Earthquake Engineering Research Institute. SCCPD=Santa Clara County Planning Department. SCCPWD=Santa Clara County Department of Public Works. SCVWD=Santa Clara Valley Water District. UCB=University of California, Berkeley. USBR=U.S. Bureau of Reclamation. USGS=U.S. Geological Survey.



* Reproducible copies of this map in greater detail are available for a small charge at the Santa Clara County Transportation Agency under the title of Relative Seismic Stability Map at a scale of one inch equals one mile.

SEISMIC ELEMENT: FIGURE FOUR

SEISMIC SAFETY ZONES*

2. geological information: fault locations and history of displacement, landslide and bedrock-surficial deposit mapping (typical data sources: CDMG, USGS);

3. geophysical information: location of faults and depth of bedrock using gravity, magnetic, resistivity, and seismic velocity surveys (typical data sources: USGS, CDMG, CDT);

4. geodetic information: tectonic creep monitoring, areal strain monitoring (typical data sources: USGS, CDMG, USBR, SCCPWD);

5. hydrologic information: flood inundation, ground water, dam safety studies (typical data sources: CDWR, SCVWD, USGS);

6. earthquake engineering research information: earthquake resistant structural design (typical data sources: UCB, CIT, EERI);

7. engineering seismology information: strong motion instrument earthquake records to earthquake-resistant design (typical data sources: USGS, UCB, CIT, SCCPWD, CDMG);

8. geotechnical site information: soil and foundation studies, seismic response studies (typical data sources: private consultants, reports found in City and County files).

RECOMMENDED HIGH-PRIORITY TOPICS FOR FURTHER STUDY

1. Active and potentially active fault zones (more precise delineation of fault traces; determination of displacement history).

2. Geologic mapping (1 inch = 1000 feet scale) along active and potentially active fault zones and potentially unstable areas.

3. Slope stability studies in critical areas (mapping of landslides and soil creep, study of landslide history, study of present natural factors and influencing future slope stability).

4. Countywide slope stability (compile data relating types, sizes and numbers of landslides and soil creep areas to such factors as geographic areas, underlying bedrock and surficial units, slope angle, relief, dominant vegetative type, and microclimate).

GENERAL GEOLOGIC SETTING

Santa Clara County is transected by the San Andreas and Calaveras fault zones (two of the major branches of the San Andreas fault system)(figure 2). The San Andreas fault zone is located near the west edge of the county in the Santa Cruz Mountains, near the boundary between Santa Clara and Santa Cruz County. The Calaveras fault zone generally bisects the county along a northwest-southeast trend through the Diablo Range. In addition, the southerly extension of the Hayward fault zone is located within the county, a few miles west of the Calaveras fault zone.

Santa Clara Valley, which includes most of the population of the County, lies between the San Andreas fault zone to the west and the Hayward and Calaveras fault zones to the east (figure 2). Many secondary faults related to these major fault zones are located throughout the mountainous areas, and some faults extend beneath the thick alluvium underlying Santa Clara Valley (see plate 1).

The distribution of bedrock in Santa Clara County is largely controlled by the San Andreas and Calaveras fault zones. The oldest rocks in the county (Franciscan Complex) occur exclusively east of the San Andreas fault zone. Also, a very large area in the Diablo Range (east of the Calaveras fault zone) is underlain almost entirely by rocks of the Franciscan Complex. Younger Cenozoic rocks (see Appendix E) occur along the margins of the Santa Clara Valley, west of the San Andreas fault zone, and in the Santa Cruz Mountains from the Loma Prieta area southeast to the Pajaro River. Brief descriptions of the various bedrock units are included on plate 1.

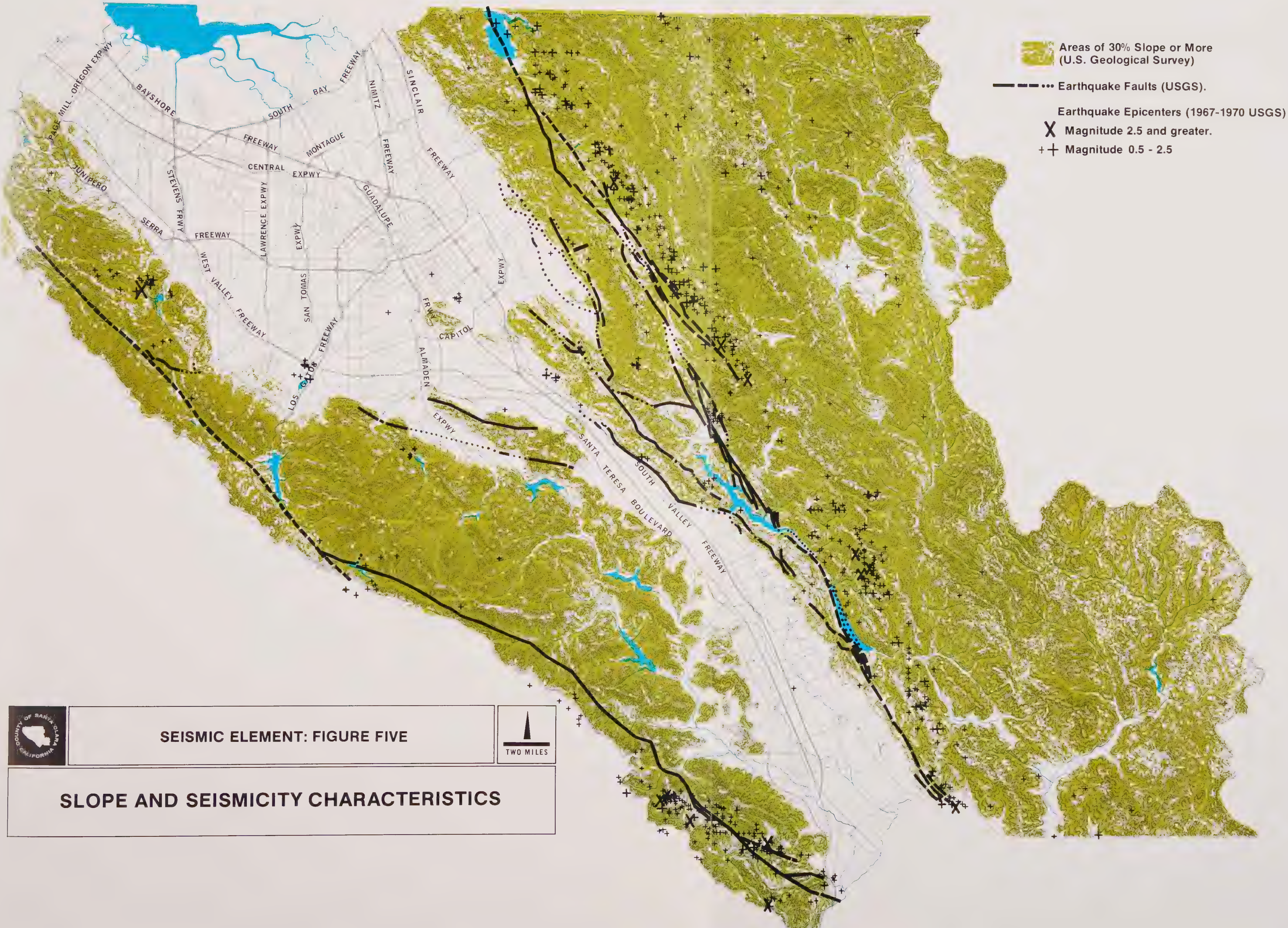
Surficial deposits (including soil, colluvium, and alluvium) occur throughout the county. Alluvium is found in the Santa Clara Valley and in many smaller stream valleys within the mountains. Colluvium, found on hillsides, generally is thicker in the Santa Cruz Mountains (due to high rainfall and extensive vegetation) and on north-facing, sun-shaded slopes (due to high moisture retention and extensive vegetation) than elsewhere in the county. Landlsides are particularly abundant in areas underlain by unstable geologic units between fault zones and in areas underlain by fractured, crushed, and sheared bedrock within major fault zones. Movement on many of the landslides, particularly along fault zones, probably was triggered at various times in the past by ground shaking during earthquakes.

EARTHQUAKE HISTORY

Since 1900, more than 1,900 earthquakes have been felt or located in or near Santa Clara County (University of California at Berkeley and California Institute of Technology earthquake catalogues). Several of these earthquakes caused damage, but many were barely noticed. See plate 2 for the location of the historic earthquake epicenters (Richter magnitude greater than 4.0) in the San Francisco Bay Area. Figure 5 shows selected seismicity and slope data.

Two local studies contain compiled data on felt earthquakes (Cupertino-Saratoga area, Rogers and Armstrong, 1973; Morgan Hill-Gilroy Area, Williams et al., 1973). Residents of the Cupertino-Saratoga area have experienced an average of four damaging earthquakes per decade since 1900, including a maximum of seven damaging earthquakes in the 1960-70 decade. Residents of the Morgan Hill-Gilroy area have experienced an average of six damaging earthquakes per decade since 1900, including a maximum of twelve damaging earthquakes in the 1950-60 decade. See details in figures 6 and 7.

Recent studies of earthquake recurrence intervals have shown that great earthquakes, such as the 1906 San Francisco event, can be expected to occur along the San Andreas fault zone in the San Francisco Bay Area every 50-150 years (Wallace, 1970; Dickinson, 1972). Thus, another great earthquake that will affect Santa Clara County can be anticipated any time within the next several decades.



SEISMIC ELEMENT: FIGURE FIVE

SLOPE AND SEISMICITY CHARACTERISTICS

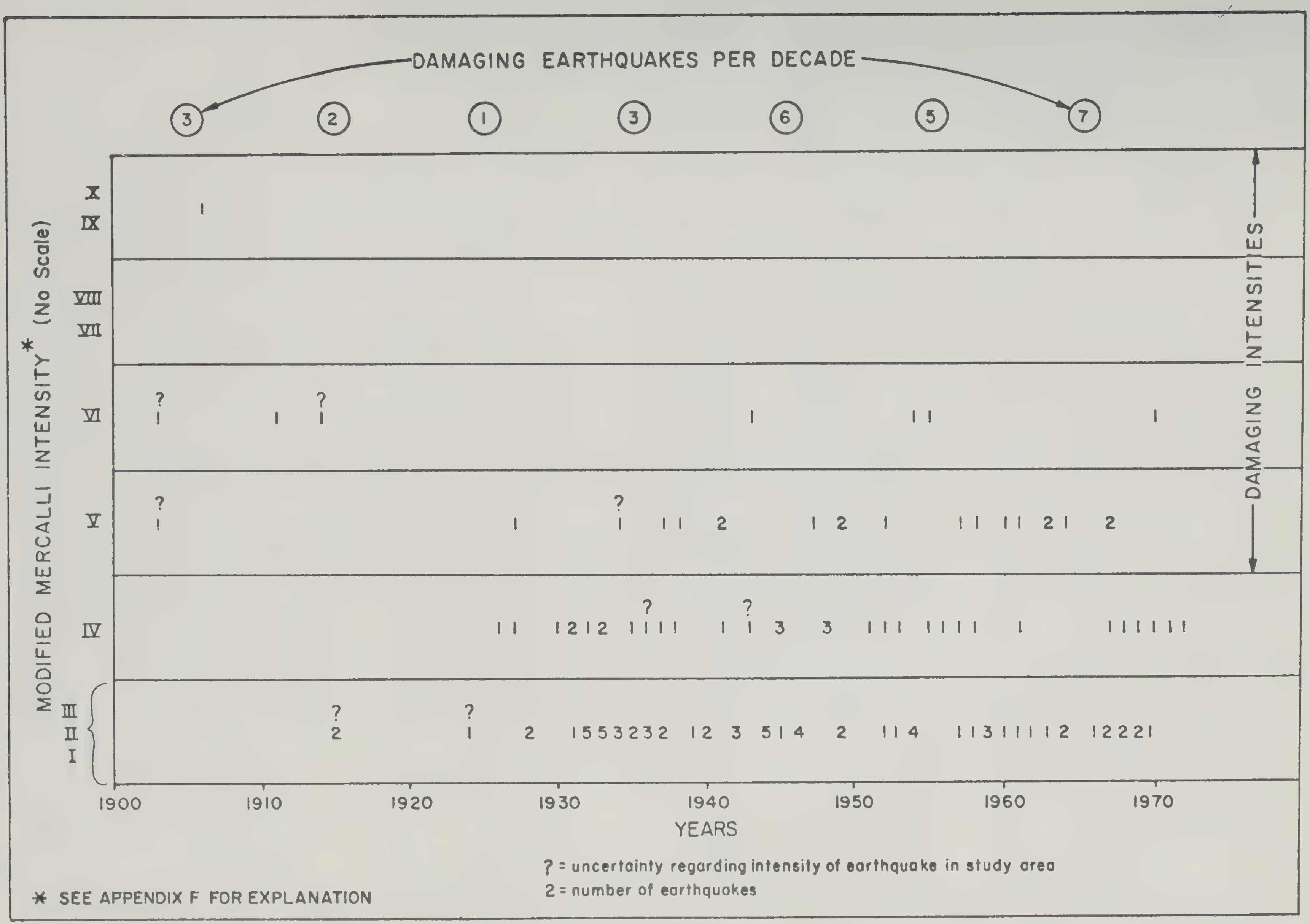


Figure 6

Earthquake History of the Monte Bello Ridge Study Area
(After Rogers and Armstrong, 1973)

Maximum earthquake intensity (Modified Mercalli Scale) felt in Gilroy-Morgan Hill area

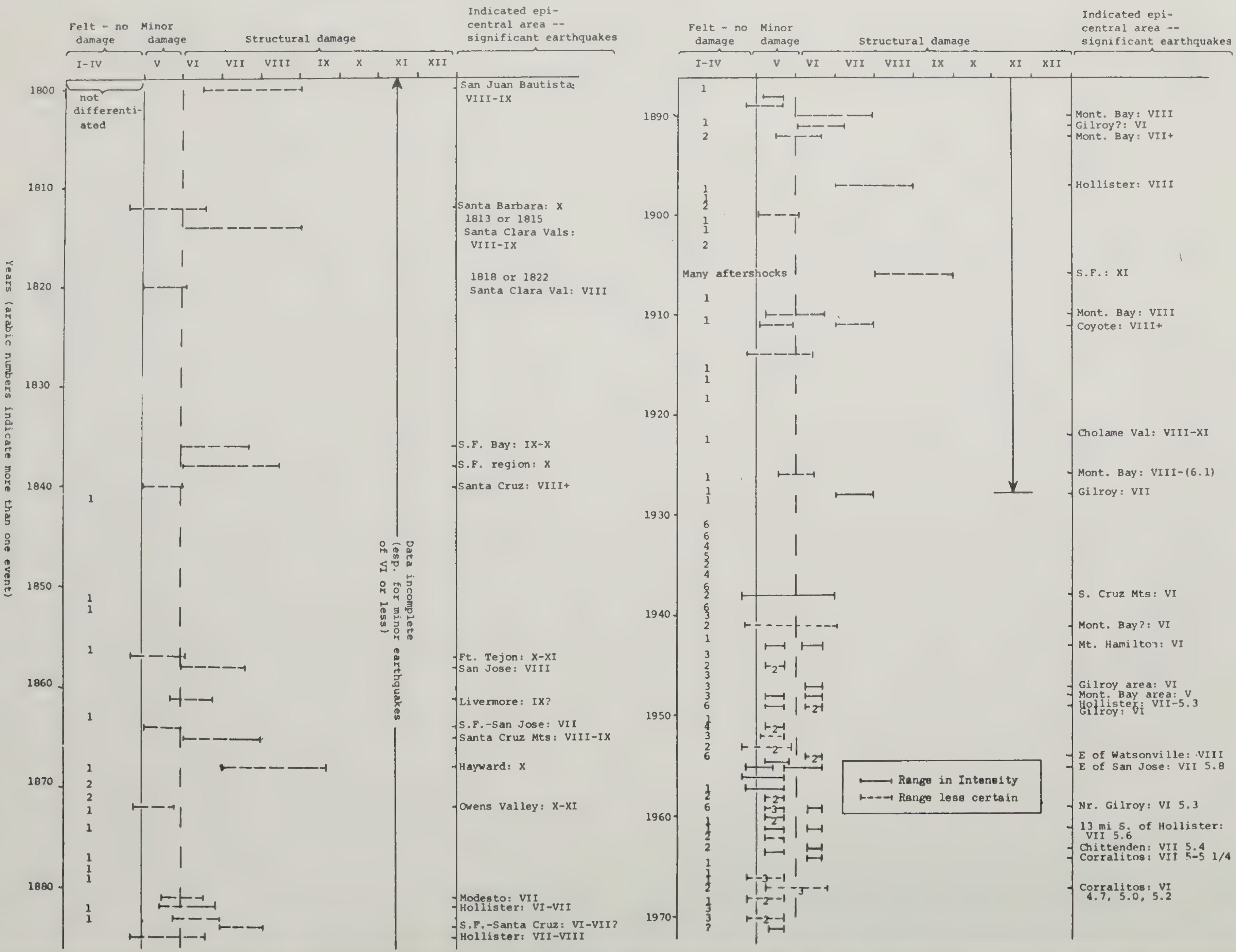


Figure 7

Measuring Earthquakes

The two most widely used scales for rating the relative size of earthquakes are the Richter magnitude scale and the Modified Mercalli intensity scale (see Appendix F). These scales measure different earthquake phenomena and can be compared only at or near the earthquake epicenter (see Appendix G).

The Richter magnitude scale is a measure of the seismic energy radiated during an earthquake. The magnitude number is calculated using data obtained from seismograph records. The range of energy represented by the magnitude scale is extremely large; for instance, an increase of one magnitude number corresponds to about a 30-fold increase in energy. Thus a magnitude 8.0 earthquake represents not twice the energy of a magnitude 4.0, but rather almost one million times the energy of a magnitude 4.0 earthquake (see Appendix F for other earthquake energy comparisons).

The Modified Mercalli intensity scale is an arbitrary rating of earthquake effects at any given location. On this scale the intensity is shown by Roman numerals (I through XII) and is estimated from human reactions and from observations of ground shaking effects and other natural phenomena (see Appendix F). These factors are not consistent so the scale is not truly quantitative, but no better scale is available (Steingrugge, 1970).

The Richter magnitude scale is most often used as a measure of the "size" of an earthquake. The modern international seismograph network can provide epicenter locations and Richter magnitudes for moderate to great earthquakes anywhere around the earth. Earthquakes in uninhabited regions, such as the ocean floor or certain areas of Antarctica, would have no Modified Mercalli ratings.

Earthquake Epicenters

Only a few of those earthquakes felt in Santa Clara County had epicenters located in the county. Epicenters of several of the major and great earthquakes were located to the north (i.e., 1906, in San Francisco and Marin Counties; 1868, in Hayward; 1836, in Hayward). Moderate and minor earthquakes that have been felt in Santa Clara County since 1910 are shown on plate 2.
Minor local earthquake epicenters located in Santa Clara County during 1969-71 are shown on plate 2.

Earthquakes and Fault Displacement

It is evident from plate 2 that epicenters of nearly all great to moderate earthquakes and most minor earthquakes are located along or on faults. Major faults extend from various depths within the earth upward to the ground surface. The intersection of the fault plane with the ground surface is called the fault trace. Minor faults may intersect ground surface or may exist entirely below ground surface.

It is generally believed that ground shaking and other earthquake phenomena are the direct result of sudden movement of blocks of the earth's crust along faults as described by Bolt (1970). Faults are thus defined as boundaries between moving blocks of rock. Widths of these blocks range from several meters

to several thousand kilometers (sometimes including entire continents). The large blocks are more correctly described as "plates" because their width is very large compared to their thickness. As an example, the San Andreas fault system seems to be a boundary between two continent-sized crustal plates, the North American and Pacific plates. These plates are drifting past each other at a slow but continuing rate of several centimeters per year. The Pacific plate is moving northwestward with respect to the North American plate. As this drift continues, strain builds up in the rocks adjacent to the plate boundary (the San Andreas fault system). Periodically this strain exceeds the rock strength, and the rocks are displaced suddenly along the fault, thus relieving the strain (see more details in Anderson, 1971). After the 1906 San Francisco earthquake (magnitude 8.3), resurveys across the San Andreas fault showed that a large area west of the fault (from Point Arena, Mendocino County, to San Juan Bautista, San Benito County, a distance of 320+ kilometers or 200+ miles) had moved 2 to 15 feet (0.7 to 4.8 meters) northwestward with respect to the area east of the fault (Lawson, chairman, 1908, v. 1, p. 114, 133).

Surface expression of such movements of large blocks, or plates, along faults is the result of major and great earthquakes at shallow depths. Smaller magnitude earthquakes are associated with displacement of progressively smaller blocks, shorter faults, and smaller displacement along the faults. For most events having a magnitude less than 5.5, displacement is entirely below ground surface, unless the focal depth is very shallow.

It is apparent from plate 2 that epicenters of many minor earthquakes are not directly associated with any mapped fault. Three possible explanations for these earthquakes are: 1) they may represent small strain adjustments far below ground surface (whether or not associated with a subsurface fault); 2) they may represent lesser activity on unrecognized faults intersecting ground surface; 3) the epicenter locations are less reliable due to incomplete data; or 4) local geologic conditions cause systematic mislocations of epicenters; for example, the alignment of epicenters east of the Calaveras fault zone probably represents activity along that fault. It is believed that a vertical band of low-velocity rocks associated with the fault zone causes a systematic mislocation of epicenters to the east (Mayer-Rosa, 1973).

POTENTIAL EARTHQUAKE HAZARDS

There are four distinct but interrelated earthquake phenomena that constitute potential hazards to a populated area. In order of generally decreasing potential for life loss and property damage, they are: 1) ground shaking, 2) ground failure, 3) ground displacement along fault traces, and 4) water inundation by earthquake-generated waves or dam failures. Depending on the topographic, geographic, and geologic features of any given populated area, this order of hazard potential may differ from the above; for example, in an area of unstable bedrock located entirely in steep mountainous terrain in an active fault zone, the potential hazard due to ground failure and ground displacement along faults may be greater than that due to ground shaking.

Ground Shaking

This phenomenon is considered to be potentially the most hazardous in most areas because: 1) it is the most widespread effect of any given earthquake,

thus affecting the most people, and 2) it is present to some extent in all earthquakes. Shaking generally decreases in severity with decreasing earthquake magnitude. In minor earthquakes (those generally less than magnitude 2), shaking is so subtle that it is usually detected only by seismographs.

The phenomenon of ground shaking as produced by a given earthquake can be described in both quantitative (measurable) and qualitative terms. Quantitative factors include duration, acceleration, amplitude, and frequency of ground motion. Earthquakes of higher Richter magnitude generally produce ground motions of longer duration, higher acceleration and amplitude, and a greater percentage of lower frequencies (Housner, 1970). Maximum acceleration is apparently less related to magnitude than the other variables. Large maximum accelerations have been recorded very close to the epicenter of some moderate earthquakes, such as Parkfield 1966 (M = 5.6, maximum acceleration = 50% gravity, Housner, 1970), Stone Canyon 1972 (M = 4.6, maximum acceleration = 70% gravity, Bufe and Tocher, 1974), and San Fernando 1971 (M = 6.6, maximum acceleration = 125% gravity, Trifunac and Hudson, 1971). Engineers use these quantitative data in the design of earthquake-resistant structures.

In qualitative terms, ground shaking can be described as of high, moderate, or low "intensity." Higher magnitude earthquakes generally produce higher shaking intensities, over wider areas which may result in greater damage intensities and be so reflected in the Modified Mercalli intensity ratings.

Factors Causing Areal Variation

During an earthquake, the intensity of ground shaking at a particular location point will depend on a number of partly interrelated variables. These include 1) earthquake magnitude, 2) shortest surface distance from the causative fault, 3) depth of earthquake focus, 4) several factors collectively referred to as "source mechanism," 5) local geologic conditions (including type and thickness of soils, surficial, and bedrock geologic units), and 6) the general topographic and geologic structural framework of the region.

At any one site, the intensity of shaking for most earthquakes is directly proportional to magnitude. Shaking intensity is inversely proportional to both the horizontal distance from the fault rupture and the depth of the focus. The deeper the focus (point of initial energy release), the smaller the amount of energy per unit of ground surface area (Steinbrugge, 1970).

The relationship of source mechanism factors and local and regional geologic conditions to shaking is complex and not well understood. This uncertain relationship and its impact on the design of earthquake-resistant buildings is currently the subject of much interdisciplinary research involving engineering geologists, soil engineers, and structural engineers. Some of this research is discussed in the following sections.

Local Geologic Conditions

Studies of many earthquakes have indicated that damage is generally greatest in areas where soils and surficial units are fine grained, compressible, and saturated with water. Conversely, damage seems to be least in areas of little or no surficial material or where bedrock is massive, hard, dry, and relatively unfractured or unweathered (MacMurdo, 1824; Wood, in Lawson, chairman, 1908; Barosh, 1969; Eckel, 1970; Steinbrugge et al., 1970).

In Santa Clara County during the 1906 San Francisco earthquake (magnitude 8.3), damage ranged from light (cracked chimneys) to severe (collapse of buildings). Many buildings collapsed at Stanford University, in San Jose and at Agnews State Hospital. In San Jose, there were "21 deaths and 10 seriously injured" (Greely, 1906). At the asylum at Agnews, 112 people were killed. Much of this building damage, particularly at Agnews, was considered to be due to "poor" construction, considered as sub-standard even by 1908 standards (Lawson, chairman, 1908 v. 1, p. 281). Water was thrown out of reservoirs near Palo Alto and out of the sulphur baths at Alum Rock. Many persons observed waves in the ground surface approximately 1 foot (0.3 meter) high. Generally, the most severe damage occurred at sites within the Santa Clara Valley and small intermontane valleys underlain by unconsolidated alluvium. In the Penitencia Creek-San Jose area, the percentage of chimneys that collapsed decreased from 90 in the Santa Clara Valley (near San Jose) to 50 near the mouth of Alum Rock. In the southern part of the county, damage was observed to be greater in the Morgan Hill-Gilroy valley area than in the mountains to the west. Even in these mountains, "houses on alluvial land suffered noticeably more than those on more solid ground." At the New Almaden mercury mines (on bedrock), the tops of two 50-foot- (15 meters) tall brick chimneys were broken off, but the brick furnaces and other facilities remained operative (Lawson, chairman, 1908 v. 1, p. 255-264, 274-276, 279-288).

This observed relationship between damage and alluvium-bedrock conditions is reflected in plate 6 (Relative Seismic Stability Map). However, ratings shown on that map reflect the combined effects of both ground shaking and ground failure. It is not certain just how much of the damage described above is related only to ground shaking; in practice the two effects usually cannot be separated.

One modern study of minor ground shaking produced by nuclear explosions and small earthquakes indicated that amplitudes of ground motion are much greater at sites underlain by fine-grained, soft, wet, surficial material than at sites underlain by bedrock (Borchert, 1970). However, ground shaking studies of the 1971 San Fernando earthquake (Magnitude 6.6) show no such consistent relationship (Hudson, 1972).

In a separate study of small earthquakes in Pasadena, Gutenberg (1957) noted 2 to 4 times greater amplitude motion on alluvium sites than on bedrock sites. At these same sites during the 1971 San Fernando earthquake, approximately the same amplitude ground motion on alluvium and bedrock was noted by Hudson (1972).

Apparently, neither the intensity nor the character of ground shaking in large earthquakes is directly predictable from ground shaking observed in small earthquakes (Hudson, 1972; Seed, 1972; Bolt, 1972; Udwadia and Trifunac, 1973).

Regional Geologic Conditions, Source Mechanism

Studies of many earthquakes at El Centro have shown that quantitative shaking characteristics are significantly different for each earthquake. These differences are probably related not only to variations in magnitude and distance from the epicenter, but also to different source mechanisms and geologic conditions along the specific travel path from epicenter to the site (Hudson, 1972; Udwadia and Trifunac, 1973).

As a corollary to the above, Seed (1972) studied one earthquake (San Fernando, 1971) at many sites. These sites were on bedrock and were generally equidistant

from the epicenter. Large variations in quantitative shaking characteristics occurred from site to site. Also, no consistent relationship between these variations and bedrock type was apparent. Therefore, a significant part of the variation seems attributable to different travel paths determined by regional geology (Seed, 1972).

Current Research

Interdisciplinary research is currently being undertaken in order to clarify some of the complexities of the problems described above. Major sources of data pertinent to such research are the quantitative records of ground shaking obtained by strong motion instruments during earthquakes. Only a few of these strong motion records are available from past earthquakes because few strong motion instruments have been in operation. Many more strong motion instrument stations need to be established so that, during future earthquakes, the shaking characteristics of various geologic foundation conditions and various structures can be measured.

Based on the state-of-the-art and the limited available data, Greensfelder (1973) has suggested that maximum bedrock accelerations of 0.5 g can be expected in the western 75 percent of Santa Clara County. The eastern 25 percent can anticipate maximum bedrock accelerations between 0.3 and 0.5 g. In time, more accurate estimates of the variation in strong ground motion during moderate and major earthquakes can be made (Seed, 1972; Borchert, 1972). Such estimates are critically important inputs in the design of earthquake-resistant structures.

In light of the above complexities, it is not feasible to construct one map of Santa Clara County showing zones of relative ground shaking characteristics expected for all future earthquakes. Seed (1974) has dealt with this problem, using the available geologic data and current state-of-the-art techniques. The geologic data pertinent to their procedures are summarized on plates 3, 4, and 5.

Ground Failure

Various processes and phenomena are grouped within the general phenomenon called ground failure. These include landsliding, liquefaction, lateral spreading, lurching, differential settlement, and bedrock shattering. All of these involve a displacement of the ground surface due to loss of strength or failure of the underlying materials during earthquake shaking.

Landslides involve downslope movement of soil and rock material. They include a wide variety of materials and mechanisms ranging from rockfalls to earth flows. A descriptive classification of landslides is shown in Appendix H. This classification applies to all landslides, whether earthquake-induced or not. Earthquake-induced landslides will occur generally in the same metastable areas as landslides induced by other natural energy sources, such as intense rainfall, and may be indistinguishable from them in appearance. The addition of earthquake energy may induce landslides that otherwise might not have occurred until a future rainy season.

Landslides on hillsides are due to failure of either surficial material (soil, colluvium) or bedrock; or both. Landslides in areas of low slope angles can result from liquefaction of subsurface sand layers during earthquakes; as in the Alaska earthquake of 1964 (Eckel, 1970; Seed and Wilson, 1967) and the San Fernando earthquake of 1971 (Youd, 1971).

Landslides usually result from a combination of factors, of both natural and human origin. Natural factors include unstable or weak rock and soil material, adversely oriented geologic structures, insufficient vegetative cover, high water content, oversteepened slopes, and high slope angles. Human factors include increase of slope angle and removal of downslope support by grading; addition of weight upslope; and addition of water by garden watering, septic tank effluent, etc. These and other factors are described in greater detail in Appendix I.

Liquefaction, lateral spreading, lurching, and differential settlement usually occur in soft, fine-grained, water-saturated alluvium, generally found in valleys.

The liquefaction process involves significant strength reduction in a buried layer of water-saturated silt or sand, resulting in a temporary quicksand condition and ground failure. Buildings with foundations resting in such layers may rotate to nearly horizontal positions or sink into the temporarily fluid layer (Seed, 1970). Also, the temporary quicksand may move as a fluid upward through vertical cracks in overlying formations to create "sand boils" at the ground surface. If the liquefied layer is completely confined so that the temporarily fluid material cannot escape, and if the time period of liquefaction is small, failure of the ground surface may not occur (Youd, 1973b).

The presence of even a modest proportion of clay in the saturated sand units is considered to be a major deterrent to liquefaction (Seed, oral communication, 1974). The clay tends to bind the sand together, reducing the potential for liquefaction.

Lateral spreading results in a dominantly horizontal displacement of flat-lying alluvial material toward an open or "free" face, such as the steep bank of a stream channel. This movement is due to failure, perhaps liquefaction, of one or more layers of alluvium exposed in the free face. In the gently sloping areas around San Francisco Bay, this type of failure will probably be the most pervasive liquefaction-related failure (Youd et al., 1973a).

Lurching, also referred to as ground fissuring or ground cracking, results in fracturing and chaotic displacement of the ground surface. Muddy or sandy water often erupts from these cracks as fountains or sheets, producing "sand boils." This may result in local subsidence and further ground fracturing (Waller, 1966). Lurch cracks also may be due to local liquefaction of subsurface material.

Differential settlement, also referred to as consolidation subsidence, results in uneven settling of the ground surface, and may be accompanied by local eruption of muddy or sandy water. Similar to lurching, this process may be due to local liquefaction or to differential compaction of alluvium or colluvium during earthquake shaking.

Each of these forms of ground failure either requires or is intensified by high water content and the presence of structurally weak materials.

Bedrock shattering can occur in hard bedrock on hillsides during earthquakes. These multiple bedrock cracks are often concentrated along narrow ridge crests between deep valleys. These cracks are probably the result of intensification of ground shaking amplitude along narrow ridge crests. Such bedrock shattering

occurred in the San Gabriel Mountains during the 1971 San Fernando earthquake (Barrows et al., 1971). The theoretical basis for, and field measurement of, this bedrock-shattering topographic effect is described by Rogers (1974).

1906 San Francisco Earthquake

The 1906 San Francisco earthquake caused ground failure in many areas of Santa Clara County. Numerous landslides (including rockfalls and various other slides) occurred in the Santa Cruz Mountains, particularly in the drainage of Stevens, Saratoga, and Los Gatos Creeks along the trace of the San Andreas fault zone. Landslides also occurred in the Diablo Range, in Penitencia Creek and other areas. Locally in the Santa Clara Valley, landslides occurred along steep bluffs adjacent to Stevens Creek.

Bedrock shattering was observed along Monte Bello Ridge in the Santa Cruz Mountains. The effects of liquefaction, lateral spreading, lurching, subsidence, and differential settlement were observed locally northeast of Mountain View and along Coyote Creek (particularly near the Alviso-Milpitas Road). Near Mountain View, the casing of an artesian well "had been shoved up 2 feet (0.6 meter), damaging the pump." Probably the ground subsided around the casing. Along Coyote Creek, lateral spreading toward the free face of the creek channel, lurching, and differential settlement caused severe damage to houses and roads. Orchard trees were displaced laterally as much as 6 feet (1.8 meters). The largest cracks were 5 feet (1.5 meters) wide, 6 feet (1.8 meters) deep, and 100 feet (30.5 meters) long. Numerous sand boils were associated with these cracks. Locally, in smaller valleys within the mountains, noticeable settling of water-saturated alluvium occurred, as in Uvas Creek Valley (Lawson, chairman, 1908, v. 1, p. 107-109, 261-262, 264, 267, 275-278, 281-283).

Probable Future Ground Failure

Areas of probable ground failure during future earthquakes in Santa Clara County are shown on plate 6 (Relative Seismic Stability Map). Because detailed and uniformly distributed borehole information was not available for the entire area, it was necessary to infer the local types of subsurface materials and their engineering properties in order to designate areas where liquefaction is a potential problem. For example, it was assumed that a sand unit was present if the water table was located close to the ground surface; such a sand unit is acting as an aquifer (either confined or unconfined, depending on the overlying materials). The presence of both water and the inferred sandy unit is sufficient reason to recommend further investigation for potential liquefaction. If the water table is at a depth greater than 50 feet, the potential for liquefaction is lessened. It is generally believed that, at depths in excess of 50 feet, the overburden pressures are such as to reduce to near zero the possibilities for liquefaction (Seed, oral communication, 1974). At any given site, water level will vary with the season; being higher during the winter wet season. Important but secondary liquefaction parameters, such as relative density and grain size distribution, have been considered by the authors in only a few locations (bridge sites, office building, etc.) because of the spotty data distribution.

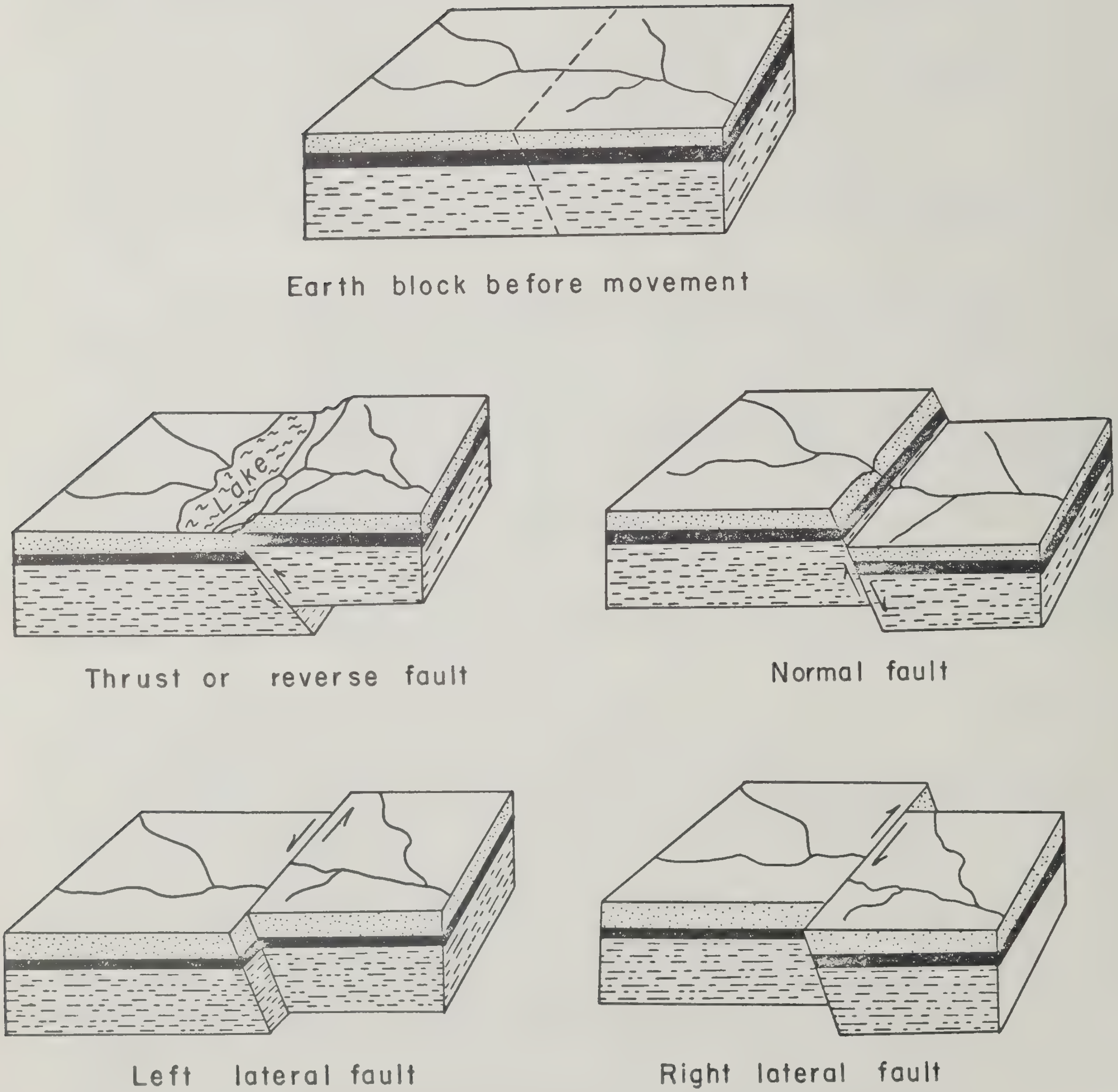


Figure 8

Examples of Some Types of Fault Displacement
(After Longwell and Flint, 1951)

Ground Displacement Along Fault Traces

Ground rupture along fault traces usually occurs during moderate, major, and great earthquakes. The length of ground rupture and amount of displacement is directly related to earthquake magnitude (Bonilla, 1970). During the 1906 San Francisco earthquake (magnitude 8.3), ground rupture occurred along 270 miles (435 kilometers) of the San Andreas fault trace (Bonilla, 1970). A maximum of 20 feet (6.1 meters) of horizontal right-lateral offset occurred near the epicenter in Marin County (Lawson, chairman, 1908, v. 1, p. 71). During the 1966 Parkfield earthquake (magnitude 5.5), 23 miles (37 kilometers) of ground rupture and less than 1 foot (0.3 meter) of right-lateral offset occurred along the San Andreas fault (Brown, 1967).

Relative displacement of the ground surface along a fault trace can be horizontal, vertical, or a combination of both, depending on the type of displacement along the fault plane. Faults are classified according to this relative displacement of the rocks on either side of the fault plane (see figure 5). Vertical displacement is involved in normal and thrust faults. Horizontal (strike-slip) displacement is involved in right-lateral and left-lateral faults.

Ground rupture along fault traces during earthquakes has been classified by Bonilla (1970) into: 1) "main fault zone," 2) "branch fault zone" (ruptures branching from the main fault zone), and 3) "secondary fault zone" (ruptures subparallel to be separate from the main and branch fault zones). The width of each of these zones depends in part on the nature of the fault displacement. Vertical fault movements tend to produce wider zones of ground rupture than horizontal fault movements. The amount of displacement along these three zones of Bonilla (1970) usually is greatest on the main zone and least on the branch and secondary zones. Also, the amount of displacement is generally greatest near the epicenter. Local patterns of ground rupture within these zones may consist of a single narrow rupture or a series of en echelon ruptures, depending on the surficial and bedrock geologic conditions.

1906 San Francisco Earthquake

In Santa Clara County, right-lateral offsets occurred along the "main zone" of the San Andreas fault ground rupture. At the intersection of Page Mill Road with the San Andreas fault, the road and fences on either side were offset "about 3 feet" (0.9 meter) across a zone 30 feet (9.2 meters) wide. Farther southeast, in Los Gatos Creek, a railroad tunnel was offset 4.5 feet (1.4 meters) across a single fracture. Small vertical displacements ranged from 0.5 to 1.5 feet (0.2 to 0.5 meter). In most of these cases, the area northeast of the fault was upthrown relative to the area southwest of the fault (Lawson, chairman, 1908, v. 1 p. 107-113).

Unverified reports were recorded concerning cracking across roads in the vicinity of the "Calaveras Valley fault-line"--now referred to as the Calaveras fault zone (Lawson, chairman, 1908, v. 1, p. 282). It is possible that a small amount of "sympathetic" movement took place along the Calaveras fault zone during the 1906 event, but this cannot be conclusively determined from the above evidence. A recent example of such "sympathetic" movement occurred in southern California during the Borrego Mountain earthquake of 1968 (magnitude 6.5). In this case, right-lateral displacement of 38 centimeters (15 inches) along the San Jacinto fault zone was accompanied by right-lateral displacement of approximately 1 centimeter (0.4 inch) on each of three other fault zones

(Imperial, Superstition Hills, and San Andreas) located 45-70 kilometers (28-43 miles) from the epicenter (Allen, 1968).

Effects of Large Land Mass Movement

Movements of large masses of land occur as a result of displacement along faults during earthquakes. The extent to which these movements become apparent on the ground surface depends on what effect the movements have on local features, such as water levels along coastlines or lakes. For example, appreciable horizontal displacement of a large landmass may occur without an apparent change in sea level. However, vertical movement of the same amount may cause obvious changes in sea level, expressed as submergence of some areas and uplift of other areas.

Such submergence and uplift can cause extensive damage to shoreline development, as documented in the 1964 Alaska earthquake (Eckel, 1970). Important secondary results of such vertical movements include increased erosion in uplifted land areas and increased sedimentation in depressed land areas, as the streams adjust their gradients to the new conditions.

In Santa Clara County, displacement of landmasses in historic earthquakes has been predominantly horizontal. However, within the last 3 million years, significant vertical displacements have occurred (Christensen, 1966). In the 1906 San Francisco earthquake, investigators pointed out that part of the "apparent" vertical displacements in several cases may have been the result of landsliding rather than vertical displacement along the fault (Lawson, chairman, 1908, v. 1, p. 107-109). For the entire 270-mile (435-kilometer) San Andreas fault displacement in 1906, a maximum of 3 feet (0.9 meter) vertical and 20 feet (6.1 meters) horizontal movement was recorded (Bonilla, 1970). A seismological study of recent earthquakes in northern and central California (Bolt et al., 1968) indicates that most rock displacements along faults have been right lateral, except in the 1957 San Francisco earthquake and a smaller event on the San Francisco peninsula in 1967, during which displacements were predominantly vertical.

Future ground displacement along faults in Santa Clara County will probably be predominantly horizontal, as in the historic past. Small amounts of vertical displacement probably will accompany large amounts of horizontal displacement during major and great earthquakes along the San Andreas, Hayward, and Calaveras fault zones. Minor vertical displacement may also occur during moderate earthquakes on local, shorter faults between the San Andreas, Hayward, and Calaveras fault zones.

Direct effects of horizontal displacement will be restricted generally to the fault zone forming the boundary between the moving landmasses. The direct effects of vertical displacement will be most noticeable along the shoreline of San Francisco Bay. The secondary effects of vertical movement (accelerated erosion and deposition) will be noticed throughout the displaced area.

Tectonic Creep

In addition to rapid displacement during earthquakes, slow sporadic displacement, called tectonic creep, can occur along active faults often without perceptible earthquake activity. The rate of tectonic creep (fault creep) may be as high as 3 centimeters (1.2 inches) per year at the ground surface (Burford et al., 1973). Tectonic creep poses a potential long-term hazard to any building or other structure located within an active fault zone. Examples of tectonic

creep damage, such as deformed structures and offset street curbs and sidewalks exist along the Hayward fault zone in Fremont (Cluff and Steinbrugge, 1966), and along the Calaveras fault zone in Hollister (Rogers and Nason, 1971).

No evidence of tectonic creep has been reported in Santa Clara County along the San Andreas fault zone (Rogers, 1972; Rogers and Armstrong, 1973), or along the Hayward fault zone. However, such displacement has been documented on the Hayward fault zone to the north, in Alameda and Contra Costa Counties (Cluff and Steinbrugge, 1966; Radbruch et al., 1966). Also, tectonic creep has been documented on the San Andreas fault zone to the south, in Santa Cruz and San Benito Counties (Tocher, 1960; Brown and Wallace, 1968; Burford et al., 1973; Wesson et al., 1973).

Fault creep is occurring along the Calaveras fault zone within Santa Clara County. Fault creep is being monitored at the Furtado site (see plate 2) southeast of Gilroy (C. Hall, U.S. Bureau of Reclamation, oral communication, 1973), and the Cochrane Bridge site (see plate 2) at the south end of Anderson Reservoir east of Morgan Hill (Radbruch, 1968; J.O. Berkland, oral communication, 1973). The displacement rate at the Furtado site from 1969 to 1972 has been 9-10 millimeters per year (0.3-0.4 inch per year). At the Cochrane Bridge site from 1950 to 1974 the apparent rate has been 0.2 inch per year (5 millimeters per year). At this site, the lack of an "as-built" survey for comparison makes calculations uncertain.

Active and Potentially Active Fault Zones

Active faults are herein defined as those faults along which future ground displacement can be anticipated. These include faults along which ground displacement has occurred in either historic time or within the most recent geologic time interval (Holocene time--about the last 11,000 years, see Appendix E). Potentially active faults are herein defined as those faults along which ground displacement has occurred within Quaternary time (about the last 3 million years). Data on potentially active faults are inadequate to indicate whether or not such displacement has occurred within the last 11,000 years. These definitions are the same as those officially adopted by the State Mining and Geology Board with reference to the Alquist-Priolo Geologic Hazard Zones Act. Presently defined active and potentially active faults in Santa Clara County are shown on plate 2.

The San Andreas and Calaveras fault zones are considered to be active fault zones in Santa Clara County. Along the San Andreas fault zone, a magnitude 8.0+ earthquake is possible, and a maximum right-lateral displacement of up to 6 meters (20 feet) can be anticipated. Along the Calaveras fault zone a magnitude 7.6 earthquake is possible, and a maximum right-lateral displacement of 3-5 meters (10-16 feet) can be anticipated (R.W. Greensfelder, oral communication, 1973; Bonilla, 1970). These estimates are based on fault length-magnitude relationships (Bonilla, 1970).

The Hayward, Silver Creek, Coyote Creek, Evergreen, Quimby, Berryessa, Crosley, Piercy, San Felipe, and Animas fault zones are regarded as potentially active. The Silver Creek fault zone has been projected northwestward from the foothills along Silver Creek across a densely populated part of San Jose. The recency of movement on this northwest projection is uncertain. Although this fault segment is suspected by many geologists to be "active" or "potentially active" (Cooper-Clark & Associates, 1974), no definite evidence of such has been found.

The gravity and magnetic investigations conducted by the CDMG for this report were inconclusive as to the activity of and precise location of the Silver Creek fault. Better definition of the fault's character might be obtained by using different geophysical techniques.

Other fault zones in Santa Clara County that are suspected of being potentially active include the Sargent and Shannon fault zones. Along the Sargent fault zone, geomorphic evidence such as sag ponds, fault troughs, and possibly fault-controlled stream reversals occurs (J.O. Berkland, oral communication, 1974). These data and indirect data, such as alignment of small earthquake epicenters, suggest that these zones may be active; thus a potential for surface rupture may exist.

The Sargent fault zone has a large number of associated small earthquake epicenters along its surface trace (see plate 2). Most of the epicenters are located either along the southern part of the mapped fault zone (from Highway 101 to an area just north of Mt. Madonna) or at the northern end of the fault zone (at its intersection with the San Andreas fault zone, near Lake Elsman). Most of this zone is within the rugged Santa Cruz Mountains, where definitive evidence of geologically recent surface movement is difficult to find.

The Shannon fault zone is associated with three isolated clusters of small earthquakes (plate 2), located 1) south of San Jose, 2) near Vasona Reservoir, and 3) west of Cupertino. The Cupertino cluster is located west of the surface trace of the Shannon fault zone. If this fault zone dips to the west as is indicated by some surface geologic data, these epicenters may represent motion on the fault zone at depth (Rogers and Armstrong, 1973; discussion in Brown and Lee, 1971). In the Cupertino area, indirect subsurface data suggest that part of the Quaternary age alluvial sediments in the Santa Clara Valley along the mountain front may be offset along the Shannon fault zone. Near the mouth of Stevens Creek, subsurface data indicate possible offset of the deeper sediment layers (greater than 350-400 feet, or 107-122 meters, below ground surface), but not the layers above the 350-400-foot (107-122-meter) depth (California Department of Water Resources, in press).

In compliance with recent State legislation (Alquist-Priolo Geologic Hazard Zones Act), the California Division of Mines and Geology has established special studies zones along fault zones considered to be active or potentially active. Regarding proposed development for human occupancy within these zones, special studies relating to earthquake hazards will be required and are to be submitted to the appropriate County officials for review. The boundaries of these special studies zones are shown on plate 6. A zone along the Sargent fault zone is currently being considered but has not been delineated.

Water Movements Generated by Earthquakes

Potential damage resulting from water movement generated by earthquakes is present in several forms in Santa Clara County. These include tsunamis, landslide splash waves, inundation resulting from dam failure, and seismic seiches.

Tsunami Hazard

A tsunami that may affect Santa Clara County could be generated locally or remotely. The most probable remote source is a major earthquake in the Aleutian area; for example, the 1964 Alaska earthquake. These waves travel from Alaska to the Golden Gate, into San Francisco Bay, and under certain conditions could overtop the dikes protecting the low-lying areas bordering the bay margins of Santa Clara County.

From analysis of past tsunami events (wave heights, source areas, frequencies, and impacts on the California coast), it seems reasonable to assume that a tsunami with a wave height of 1 foot will arrive at the Golden Gate approximately every 6 years and that a tsunami with a wave height of 8 feet will arrive at the Golden Gate every 100 years (E.E. Welday, oral communication, 1974). The largest wave height recorded at Fort Point, beneath the Golden Gate Bridge, was 7.4 feet in 1964 (equivalent to wave amplitude of 3.7 feet). Amplitude is the critical wave feature to be considered in possible overtopping of the Santa Clara County dikes.

By the time a wave has reached the southern end of San Francisco Bay, frictional forces have reduced the wave amplitude to approximately one-tenth of the amplitude at the Golden Gate. In the above case of the maximum wave at Fort Point, the amplitude at San Jose, had it been measured, would have been about 0.4 foot. If a wave of 0.4 foot amplitude occurred at maximum high tide (a time when there is little freeboard at the dikes), the additional water height generated by the tsunami could overtop the dikes, causing flooding (Tudor engineering, 1973). If, at the same time, bay water elevation and/or large runoff from local storms was increased by northerly wind waves--the chance for overtopping would be increased.

Several additional factors are increasing the potential for overtopping and inundation. First, sea level is rising and has risen about 0.7 foot during the past 50 years (Thurlos, 1973). Second, the bay margins are subsiding, in part the result of ground water withdrawal. Although the subsidence due to ground water withdrawal has been essentially stopped, anticipated future water needs may require additional withdrawal, causing additional subsidence (Cooper-Clark & Associates, 1974). Third, tectonic forces are causing subsidence, although at a much smaller rate than the ground water withdrawal. Although these factors are small, they are nevertheless cumulative and further reduce the already critical amount of freeboard the dikes offer as protection from tsunamis or from wind-generated waves.

As soon as a particular distant seismic event is detected, tsunamis are predictable as to height, time of arrival, and period. Precautions can be taken on the receipt of a tsunami alert. It takes approximately 5 hours for a wave to travel from Alaska to the central parts of the California coast.

A locally generated tsunami could occur as the result of a local earthquake involving a significant vertical movement along a fault under San Francisco Bay. Most of the movement on faults in this part of California has been lateral, but vertical motion has been recorded. If large vertical motion occurred along a fault under San Francisco Bay, a tsunami could be generated within the confines of the Bay. At present, no active or potentially active faults are known to exist under San Francisco Bay. Thus the probability of such an occurrence is considered to be very low.

In the eastern parts of Santa Clara County, the Calaveras, Anderson, and Coyote Reservoirs are underlain by the active Calaveras fault zone. Some potential for some vertical displacement exists along this fault zone. A propagating wave of water could be generated in the reservoirs that could cause damage to development along the reservoirs' margins.

Inundation Resulting from Dike Failure A local major or great earthquake could cause the failure of parts of the bay margin dike system as described by Tudor Engineering (1973) and Bonilla and Gates (1961). Such failure could lead to the flooding of those areas presently below sea level. The dikes were constructed of locally derived weak materials and were designed only to retain salt pond water under static conditions and not to serve as protection for populated areas.

The maximum limit of salt water flooding that could follow dike failure can be estimated using the worst possible combination of circumstances. This maximum water height amounts to approximately 10 feet above mean sea level. Of this 10 feet, 4.5 feet can be attributed to the maximum diurnal range in the tide, 2 feet to low barometric pressure and storm surge, 3 feet to storm waves, and 0.5 foot to tsunami (remotely generated). The water height could be raised an unknown additional amount by fresh water flooding (fresh water from excessive runoff floating on the salt water). Because of the very small probability of all these additive events occurring at the exact time of dike failure, a more realistic value of 5 feet (the approximately maximum diurnal range of the tide) has been selected to delineate the zone of flooding in the event of dike failure. This value should not be taken as an absolute, for, as indicated above, the flooding limit can reach higher values (10 feet) as the result of the combination of unusual circumstances. This 10-foot elevation may not correspond to the 10-foot contour shown on U.S. Geological Survey topographic maps because of recent local land subsidence.

Landslide Splash Hazard If a large earthquake-triggered landslide rapidly entered a reservoir or lake, a landslide splash wave could be generated causing damage to shoreline development. The potential for this is greatest at reservoirs adjacent to steep slopes underlain by unstable rocks and soil materials. Factors to be considered in an evaluation at a specific site include length of time that the reservoir is full or nearly full, depth of water, and areal configuration of the water surface (T.I. Iwamura, oral communication, 1974).

A higher than average potential for landslide splash waves exists at the following reservoirs: Stevens Creek, Lexington, Lake Ranch, Howell, Anderson, Coyote, and Pacheco. Ancient landslides (some of very large dimensions) exist on slopes adjacent to these reservoirs. Major earthquakes could rejuvenate large parts of these landslides. At Lake Elsman, Williams, Calero, Almaden, Guadalupe, Chesbro, Uvas, and Calaveras Reservoirs, the potential for landslide splash waves is lower because of the greater stability of the adjacant slopes.

Inundation Resulting from Dam Failure Should a dam fail during an earthquake, the released water may cause flooding downstream, depending partly on the rate of water release and the quantity of water in the reservoir. Failure of a dam could be caused by ground displacement along a fault trace, ground shaking, or overtopping of the dam by a large landslide splash wave.

The extent of downstream flooding from postulated dam failures at most reservoirs in Santa Clara County has been delineated by the Santa Clara Valley Water District, in response to recent State legislation (SB 896, enacted as Chapter 780, 1972 Statutes). These inundation maps assume a maximum catastrophe resulting from full reservoirs, partial failure of the dam (based on configuration of the stream section), and staged release of the impounded water (T.I. Iwamura, oral communication, 1974).

Dam failure to ground displacement along a fault trace is most likely to occur at Lake Ranch, Howell, Coyote, and Calaveras Reservoirs. Dams of these reservoirs are located astride the most active traces of the San Andreas fault zone (Lake Ranch, Howell) or Calaveras fault zone (Coyote, Calaveras).

Dam failure due to ground shaking is difficult to assess. Given the present state-of-the-art, it is very difficult to state whether or not any dam in the county is more vulnerable to ground shaking than another. Overtopping of dams by landslide splash waves may possibly occur at the reservoirs mentioned above that have a high landslide splash hazard potential.

All aspects of potential dam failure are under active study by the California Division of Safety of Dams, which is responsible for the surveillance and certification of dam safety. The data in this and previous geologic studies in Santa Clara County have been forwarded to the Division of Safety of Dams for their consideration.

Seiche Hazard — The parameters for earthquake-generated seiche in its true form (a standing wave) appear to be partly met in one reservoir in the county. The parameters are deep water, steep straight sides, and a thick layer of unconsolidated sediment on the reservoir bottom. Coyote Reservoir has a steep east side, deep water (when full), but only a thin veneer of unconsolidated sediment on the reservoir bottom.

If a seiche is generated at Coyote Reservoir, damage to shoreline development could occur. Because of the steepness of the slopes above the reservoir on the eastern side, there is little probability that much development will take place there. Wave runup heights should be less on the west than on the east because the gently inclined western slope and irregular shoreline should generally dissipate the wave energy.

During the great earthquake of March 27, 1964, in Alaska, seismically-induced seiches were observed in many parts of the North American continent. Outside of Alaska, the maximum wave height recorded was 1.83 feet at a lake in Michigan (Vorhis, 1967). Within Alaska, the highest waves recorded were at Kenai Lake; 7 feet, 8.5 feet, and "about 10 feet." Damage along the shoreline at Kenai Lake reached various heights above lake level (11 feet, 20 feet, 30 feet) due to wave runup in some constricted channels (McCulloch, 1966).

INTERPRETATION

The basic data described above are summarized and generalized on plate 6 (Relative Seismic Stability Map). This interpretive map is intended to be a planning tool that will help to maximize the awareness of potential geologic hazards and minimize the loss of life and property during future earthquakes.

RELATIVE SEISMIC STABILITY MAP

The zones on this map identify specific site investigation requirements (plate 6). These zones are essentially a composite threefold classification of potential geologic hazards and their general locations in Santa Clara County (zone D--high hazard areas; zone E--moderate hazard areas; zone F--low hazard areas). Geotechnical site investigations are most needed in zone D and least needed in zone F. The relative hazard zones are defined in terms of specific geotechnical problems that should be considered by such site investigations.

Zone D

The hazards in this zone include one or more of the following: 1) High potential for liquefaction and associated forms of ground failure; for example, lateral spreading and lurching (Dl); 2) High potential for liquefaction and differential settlement (Dc); 3) High potential for ground rupture along "active" fault traces (Dr); 4) High potential for inundation should a tsunami overtop the bayside dikes (Df).

Areas of potential liquefaction are located in valleys underlain by alluvium. Materials subject to liquefaction consist of clean (nonclayey), fine-grained water-saturated unconsolidated sands or silts within 50 feet (15 meters) of the ground surface. High liquefaction potential exists where such materials occur within 20 feet (6 meters) of ground surface. Locally, some of these sands are saturated by water only during the winter rainy season. If an earthquake should occur during the summer, when the water table is lowered, the liquefaction potential would be considerably reduced.

Lateral spreading and lurching will most likely occur in areas adjacent to steep stream banks or other near-vertical "free faces."

Differential settlement is most likely to occur in areas underlain by thick, compressible, water-saturated deposits (bay mud or swamp deposits). In a recent environmental analysis of the Hayward shoreline area, Goldman (1973) concluded that, in areas underlain by more than 5 feet (1.6 meters) of bay mud, development should be discouraged because of anticipated severe damage during a major earthquake. Zone D includes areas underlain by compressible deposits estimated to be thicker than 5 feet (1.6 meters).

Areas of high potential for ground rupture along faults are those areas delineated as Special Studies Zones in accordance with the Alquist-Priolo Geologic Hazard Zones Act. In Santa Clara County, these zones are located mostly in hillside areas. High potential for earthquake-induced landslides exists in hillside areas where there are existing landslides and where slopes steeper than 15 percent are underlain by bedrock units of low stability.

Zone E

This zone includes areas of moderate potential for liquefaction (El) and areas of moderate potential for earthquake-induced landslides (Es).

Moderate liquefaction potential is believed to exist in valleys where clean granular alluvial material is generally saturated with water at depths between 20 feet (6 meters) and 50 feet (15 meters).

Moderate landslide potential exists in hillside areas where slopes steeper than 15 percent are underlain by bedrock units of moderate stability and where slopes less than 15 percent are underlain by bedrock units of low stability.

Zone F

This zone has a low potential for liquefaction (Fl) and for earthquake-induced landslides (Fs). Low liquefaction potential is believed to exist in hillside areas and in valleys where the water table is generally greater than 50 feet (15 meters) deep. Low landslide potential exists in hillside areas where slopes less than 15 percent are underlain by bedrock units of moderate stability and where all slopes are underlain by bedrock units of high stability.

LIMITATIONS

This map is subject to the same limitations as noted in Appendix B. As more data becomes available and as the state-of-the-art advances, revisions of this map will be necessary.

This map does not directly reflect the potential hazard of ground shaking which is being analyzed for Santa Clara County by H. Bolton Seed. Close liaison has been maintained with Seed to achieve consistency of purpose and products. For a fuller assessment of geotechnical earthquake problems, the studies should be considered together.

NON-SEISMIC CONDITIONS

The geologic stability of an area can influence land development choices under static as well as seismic conditions. Quite often those areas shown as potentially hazardous under earthquake conditions are also hazardous without an earthquake, but hazards may occur over a longer period of time as compared to an abrupt catastrophic happening.

Each year the rainy season will cause some changes in the shape of the land. The increased weight of the moisture can bring down an unstable land mass as a landslide or mudslide. Heavy rainstorms may erode new and/or deeper gullies. Most of these natural earth processes can be triggered or accelerated by careless works of man through road cuts, grading, additional loads, removal of vegetation, and misdirected drainage.

Subsidence

The influence of man through ground water withdrawal over a number of years has been largely responsible for regional land surface subsidence first detected in Santa Clara County in 1912. The elevation of land surface has decreased 9 feet near Sunnyvale and over 12 feet in San Jose. While the rate of subsidence has slowed down significantly by the ground water recharge program, the decreased elevation has increased the amount of baylands area subject to salt water flooding if the salt pond levees were to fail. A PPC Baylands report on Geology and Structural Engineering (1970) stated:

> "As subsidence takes place, the land behind flood-control and tide-control dikes becomes lower, and the dike must be raised. This condition creates the dual effect of increasing the consequences of dike failure, because of the greater potential flood, and decreasing the stability of the dike system, because of greater weight."

Expansive Clays

Expansive clays are a poor foundation material because they swell when wet and shrink when dry, producing extensive cracks. "The expanding clay has enormous power to move the foundations of even heavy structures placed directly upon it. Since the movement is not uniform, such foundations became cracked and the supported structure damaged. These movements are repeated during each new wet-dry cycle in the clay with the result that damage to the structure increases with time. Expansive clays are commonly encountered in developments, and methods used to overcome their effects on structures have become standard practice." (PPC Baylands Geology and Structural Engineering) Past damage to structures due to expansive clays has been severe and the phenomenon continues to be one of the major hazards in developing flatlands. However, the effects of these clays have been partly mitigated by soils engineering studies required of subdivisions by the Subdivision Map Act.

Peat and Other Organic Soils

There are a few areas in the County that are composed of peat and other highly organic soils. These soil types are often found in existing or former low marshy areas, so the organic material is the result of partly decomposed

vegetation. The major problem with peat and other organic soils is their high compressibility. "Fibrous soils like peat cannot be compacted by any feasible means and are not usually utilized as foundation material. Where peaty soils are drained, oxidation takes place producing a loss in soil volume and resulting in ground subsidence. Such a process is a major problem in the Sacramento-San Joaquin delta area where some 350,000 acres are affected by subsidence reaching a maximum of more than ten feet. Subsidence due to oxidation of peaty soils in Santa Clara County should involve relatively small areas. However, the effect is exaggerated where fills are placed over compressible, soft organic layers; and the combined weight of the fill material and the building may result in serious settlement. Structures on organic soils or on fills over organic soils must be designed with these unfavorable characteristics very clearly in mind." (Engineering, Soil Classification for Residential Developments, FHA 1961) See Figure 9 for former marshland areas.

Bay Mud or Soft Clay

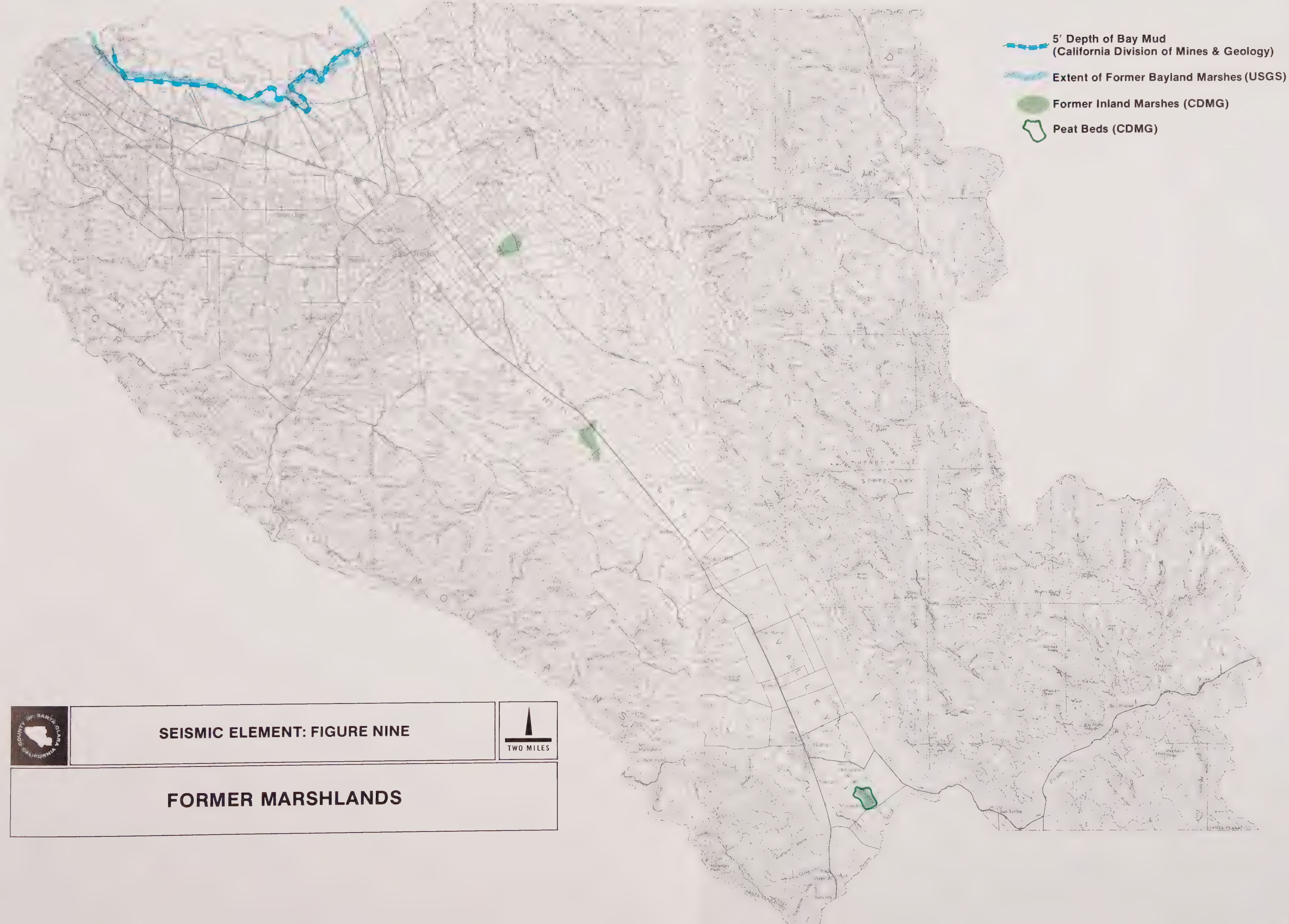
Bay mud is a very weak and compressible poor foundation material that cannot support structures placed directly upon it.

> "A layer of well-compacted, good quality fill must be placed over bay mud to provide sufficient foundation support for even light structures or roadways. Heavy or sensitive structures must be supported on deep foundations that extend through the bay mud deposit and into underlying alluvial soils that have sufficient bearing capacity.
>
> "Dikes, embankments, and fills placed on bay mud must be constructed with great care. Very gentle and flat slopes are necessary to prevent the creation of 'mud waves' and slope failures during construction. In addition, fills should be placed slowly and uniformly over the area to be filled.
>
> "The compressible nature of bay mud allows it to consolidate greatly under the weight of fill and structures, and settlement of the land surface occurs. Uniform settlement is generally not detrimental to buildings, streets, or utility lines; however, dikes may settle below high-water levels and, thus, be affected. Non-uniform or differential settlement, however, can be very detrimental to buildings and utility lines and is a major concern during development of bay-mud sites.
>
> "Differential settlements may be caused by non-uniform thickness of bay mud or overlying fill, or by a change in composition within the mud. These conditions leading to differential settlement are very likely to be present in the Baylands because of the elaborate system of meandering sloughs in the marshlands that represent waterways for the ebbing and flowing tides. As these meanders change location, they may be backfilled by very soft bay mud, by sand, or by peat deposits, and be difficult to recognize at the surface. Fill that might be placed over such an abandoned meander could experience differential settlements as a result of these changing conditions." (PPC Baylands Geology and Structural Engineering)

Uncontrolled Solid Waste Sites

"The magnitude of settlement and differential settlement that can be expected in an uncontrolled dump fill is not necessarily any greater than that which might be experienced at a site underlain by bay mud. However, the behavior of uncontrolled dump fills is very erratic and unpredictable because of the great variation in their composition and denseness.

"Structures located on uncontrolled dump fill must be supported on pile foundations extending through the fill into bearing soil. The heterogeneous nature of the fill, which may include concrete, auto bodies, trees, and brick, makes installation of piles very difficult and costly. Settlement of the fill relative to the pile-supported structure also creates problems with respect to utility connections, surface drainage, and access to the building." (PPC Baylands Geology and Structural Engineering)



SEISMIC ELEMENT: FIGURE NINE

FORMER MARSHLANDS

SOIL AND GEOLOGIC EFFECTS ON BUILDING DAMAGE DURING EARTHQUAKES

Introduction

The response of a site during an earthquake, and the building damage which may ensue, can be influenced in a number of ways by the geologic and soil conditions underlying the ground surface. Clearly, if the site is traversed by a fault along which rupture occurs, different parts of the site may be subjected to abrupt differential movements up to 20 feet or so in magnitude. Normal buildings cannot be designed to withstand movements of this type and the only recourse to prevent severe damage under these conditions is to ensure that structures do not overlie active faults. Even where this is not the case, however, and a fault cuts through an urban area, the earthquake damage due to fault movements is likely to be only a very small fraction of the total damage. In the San Fernando earthquake of 1971, for example, where the fault break extended through a major built-up area, the damage due to faulting has been estimated to be only 1 or 2 percent of the total damage caused by the earthquake. More important causes of damage are likely to be ground instability leading to settlements of buildings, or landslides and slope failures, and the damaging effects of the earthquake shaking on buildings and structures of all types.

Soil Instability

In some areas, the ground shaking resulting from the earthquake may lead to a gross instability of the soil formations, resulting in large permanent movements of the ground surface and associated distortion of structures supported on it. Thus for example deposits of loose granular soils may be compacted by the ground vibrations induced by the earthquake, resulting in large settlements and differential settlements of the ground surface. An island near Valdivia, Chile, for example, was partially submerged as a result of the combined effects of tectonic land movements and ground settlement due to compaction in the Chilean earthquake of 1960, while parts of Niigata, Japan were inundated when settlement of ground adjacent to a river occurred in the Niigata earthquake of 1964.

In cases where the soil conditions consist of loose saturated granular materials, the tendency to compact may result in the development of excess hydrostatic pressures of sufficient magnitude to cause liquefaction of the soil, resulting in settlements and tilting of structures. Liquefaction of loose saturated sand deposits resulted in major damage to thousands of buildings in Niigata, Japan in the Niigata earthquake of 1964 (Ohsaki, 1966).

Again, the combination of dynamic stresses and induced pore water pressures in deposits of soft clay and sands may result in major landslides such as that which developed in the Turnagain Heights area of Anchorage, Alaska in the earthquake of March 27, 1964 (Seed and Wilson, 1967). The coastline in this area was marked by bluffs some 70 feet high sloping at about 1 on $1\frac{1}{2}$ down to the bay. The slide induced by the earthquake extended almost 2 miles along the coast and extended inland an average distance of about 900 feet. The total area within the slide zone was thus about 130 acres. Within the slide area the original ground surface was completely devastated by displacements which

broke up the ground into a complex system of ridges and depressions. In the depressed areas the ground dropped an average of 35 feet during the sliding. Houses in the area, some of which moved laterally as much as five or six hundred feet as the slide progressed, were completely destroyed. Major landslides of this type have been responsible for much damage and loss of life during earthquakes.

While these types of soil instability may cause catastrophic damage to buildings, it should be recognized that they can only develop in areas where soil conditions and local topography are unfavorable. Such situations can now be recognized in the main by appropriate soil investigations and geologic reconnaissance and appropriate steps taken to ameliorate their effects, or to foresee the consequences of the damages which may result.

While it is not possible from the general information available in Santa Clara County to designate areas where excessive ground settlement and landsliding may occur, it is possible to make general assessments of the potential hazards due to soil liquefaction. Such assessments must be based on available information concerning the presence of loose to medium dense sand layers in the soil profile, particularly within the top 50 feet, and the depth of the ground water table. From this type of information, the various grid zones in figure 10 have been designated in one of four categories with regard to liquefaction potential:

NALP	No apparent liquefaction potential
PNLP	Probably no liquefaction potential
PL-RI	Possible liquefaction--requires investigation
DITALP	Data insufficient to assess liquefaction potential

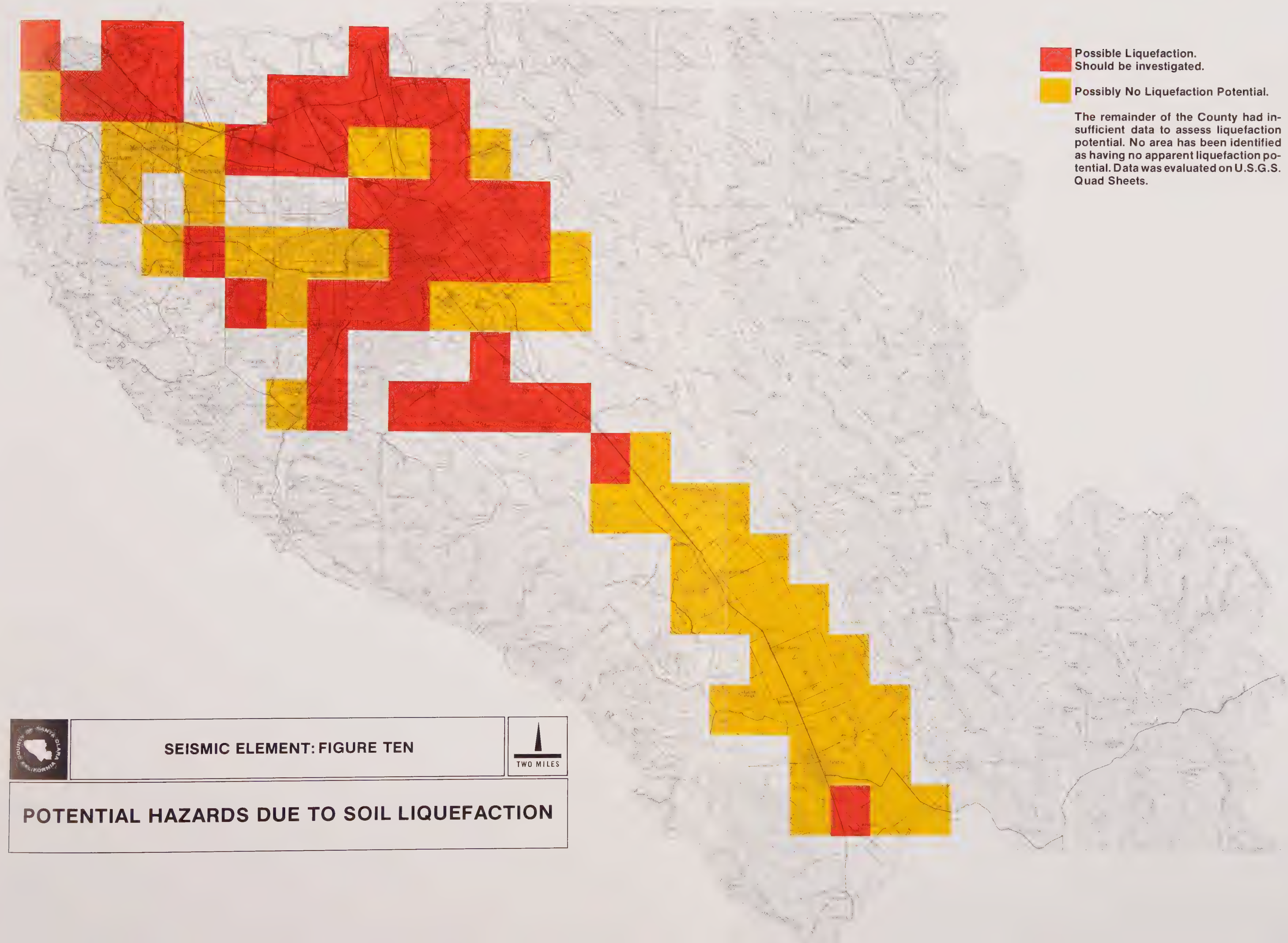
While there can be no assurance that individual sites within any zone necessarily qualify for these ratings, it is believed that the ratings generally reflect the probable area performance due to strong earthquake shaking of the type which may be expected in Santa Clara County.

Effects of Local Soil Conditions on Damage Due to Shaking

It has long been recognized that the intensity of ground shaking during earthquakes and the associated damage to buildings are profoundly influenced by local geologic and soil conditions. MacMurdo (1824), in describing the effects of the earthquake near the Runn of Cutch, India, in 1819 noted that "Buildings situated on rock were not by any means so much affected by the earthquake as those whose foundations did not reach to the bottom of the soil."

Inferential evidence that the soil conditions underlying a site can have a substantial effect on the intensity of ground surface motions was also presented by Wood (1908) in his study of the distribution of damage and apparent intensity of shaking in the San Francisco Bay Area during the earthquake of 1906. Since that time a number of investigators, for example Gutenberg (1957) and Borcherdt (1970) in the United States and Kanai et al. (1954, 1959) in Japan have shown that during small earthquakes and micro-tremors and explosions, the ground surface motions on soil deposits are often considerably higher than those occurring on adjacent rock exposures.

A comprehensive study of the effect of site conditions on the intensity of strong earthquake motions at widely separated sites in different earthquakes



SEISMIC ELEMENT: FIGURE TEN

POTENTIAL HAZARDS DUE TO SOIL LIQUEFACTION

was made by Wiggins (1964). However, it has only been in the last 15 years or so that strong motion instrumental records have been obtained at a number of locations in the same general area to show the major effects of variations in local soil conditions on the characteristics of ground surface motions. In the 1957 San Francisco earthquake, for example, recordings of ground motions were made at several locations within the city. Using the recorded motions as a basis for analysis, computations show that the maximum base shear for a typical 10-story building located at each of the recording sites would vary by several hundred percent, from a low value of about 200 kips for sites underlain by rock or shallow soil to values as high as 900 kips at a site underlain by about 300 feet of clay and sand. Clearly it is necessary to be able to anticipate variations of this magnitude at the design stage by appropriate zoning of local areas.

Probably the most detailed investigation of the relationship between building damage due to ground shaking and soil conditions was that made for Caracas following the Caracas earthquake of 1967. Although the magnitude of the earthquake was only about 6.4 and its epicenter was located about 35 miles from Caracas, the shaking caused the collapse of four 10- to 12-story apartment buildings with the loss of over 200 lives. Many other structures suffered structural damage and severe architectural damage.

A detailed study of the relationship between structural damage to buildings and the depth of the underlying soils (Seed and Alonso, 1974) showed that for 3- to 5-story buildings, damage was many times greater where soil depths ranged from 30 to 50 meters than in deeper deposits. For 5- to 9-story buildings, the structural damage intensity was slightly higher for soil depths of 50 to 70 meters than for other depths of soil, but for buildings over 10 stories high, the structural damage intensity was several hundred percent higher where soil depths exceeded 160 meters than for soil depth below 140 meters. Again, it is apparent that for tall buildings, the depth and characteristics of the underlying soil deposits had a very large effect on the severity of ground motions and the resulting building damage, even in the same city and for the same earthquake.

In both of the above examples it should be noted that the response and damage to tall buildings was greatest where they were located on deep soil deposits. In Caracas (1967) as well as in other earthquakes (e.g. Skopje, 1963) it has been observed that damage to low stiff structures was highest where they were found on shallow soil deposits. Thus both theory and performance observations have led to the conclusion that building damage due to shaking tends to be maximized when the natural period of vibration of a building is similar in magnitude to the characteristic period of the ground on which it is constructed; in such cases a sort of pseudo-resonance can occur which leads to increased response and higher damage potential. On the other hand, where the natural period of vibration of a building is quite different from the characteristic period of the underlying soil formations, response and damage potential tends to be appreciably reduced.

Recognition of this principle has led to a recent proposal by the Structural Engineers Association of California for revision of the Uniform Building Code to make the design lateral force coefficient, directly proportional to a structure-site resonance coefficient, S. The value of S varies from 1 to 1.5 depending on the ratio T/T_s where T is the natural period of the structure and T_s the characteristic period of the soil deposit at the building site. In

this proposal values of S would be determined by the equations:

$$S = 1.0 + \frac{T}{T_s} - 0.5 \left(\frac{T}{T_s}\right)^2 \qquad \text{when } \frac{T}{T_s} \leq 1$$

and

$$S = 1.2 + 0.6 \frac{T}{T_s} - 0.3 \left(\frac{T}{T_s}\right)^2 \qquad \text{when } \frac{T}{T_s} > 1$$

A plot of the relationship between S and $\frac{T}{Ts}$ is shown in Figure 11, and it seems desirable that such values of S should be incorporated in building design practice in Santa Clara County. In order to implement this approach it is necessary to determine values of T_s. While the appropriate value for any individual site will depend on specific details of the underlying soil conditions, it is possible to estimate probable ranges of T_s for the various grid zones on the basis of generalized information. Such ranges are shown in the grid zone map* and it is believed that they are of sufficient accuracy for planning purposes; individual site studies will be required for design, however.

Statistical analyses of the response characteristics of strong motion records also show a significant variation with local soil conditions (Seed et al., 1974). Thus spectral accelerations for deep or soft deposits tend to be considerably higher in the long period range than those for stiff deposits, while spectral accelerations for stiff deposits tend to be somewhat higher than those for deep or soft deposits in the low period range. Typical variations in the forms of the acceleration response spectra for different types of soil conditions in an area of very strong earthquake shaking are shown in Figure 12. Relative spectral shapes are shown for 4 soil and rock conditions, designated A to D as follows:

A -- Deep stiff soils with some overlying bay mud

B -- Deep stiff soils (>300 feet) with no bay mud

C -- Stiff soil deposits less than 200 feet deep

D -- Rock.

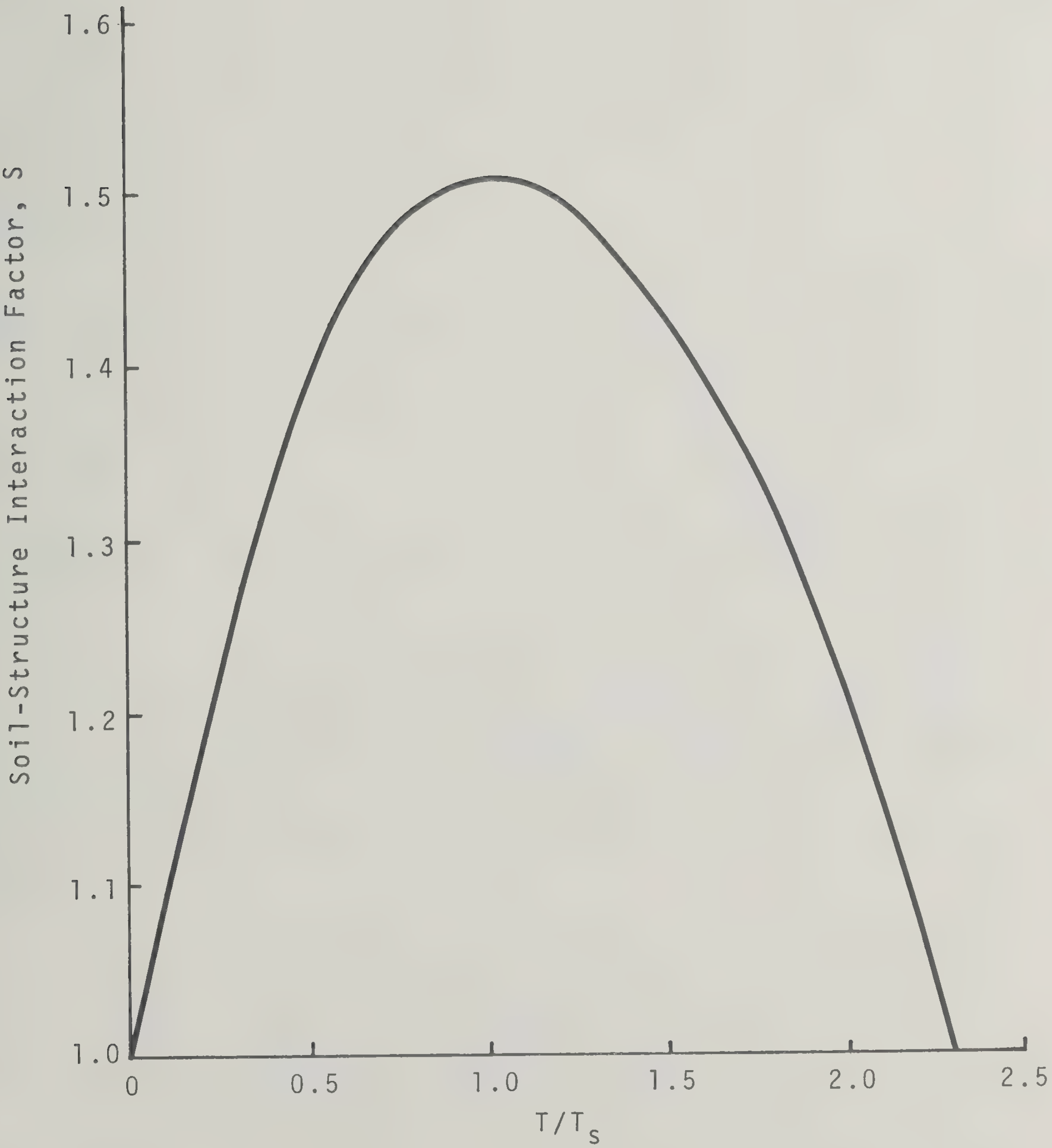
Spectral shapes to be expected in the various grid zones in Santa Clara County are indicated on the map. In grid zones encompassing a wide range of soil conditions, only the possible ranges of spectral shapes are indicated.

With the aid of this information it is believed that improved seismic design criteria for structures can be implemented and improved judgment made regarding the potential hazards from earthquake shaking.

---

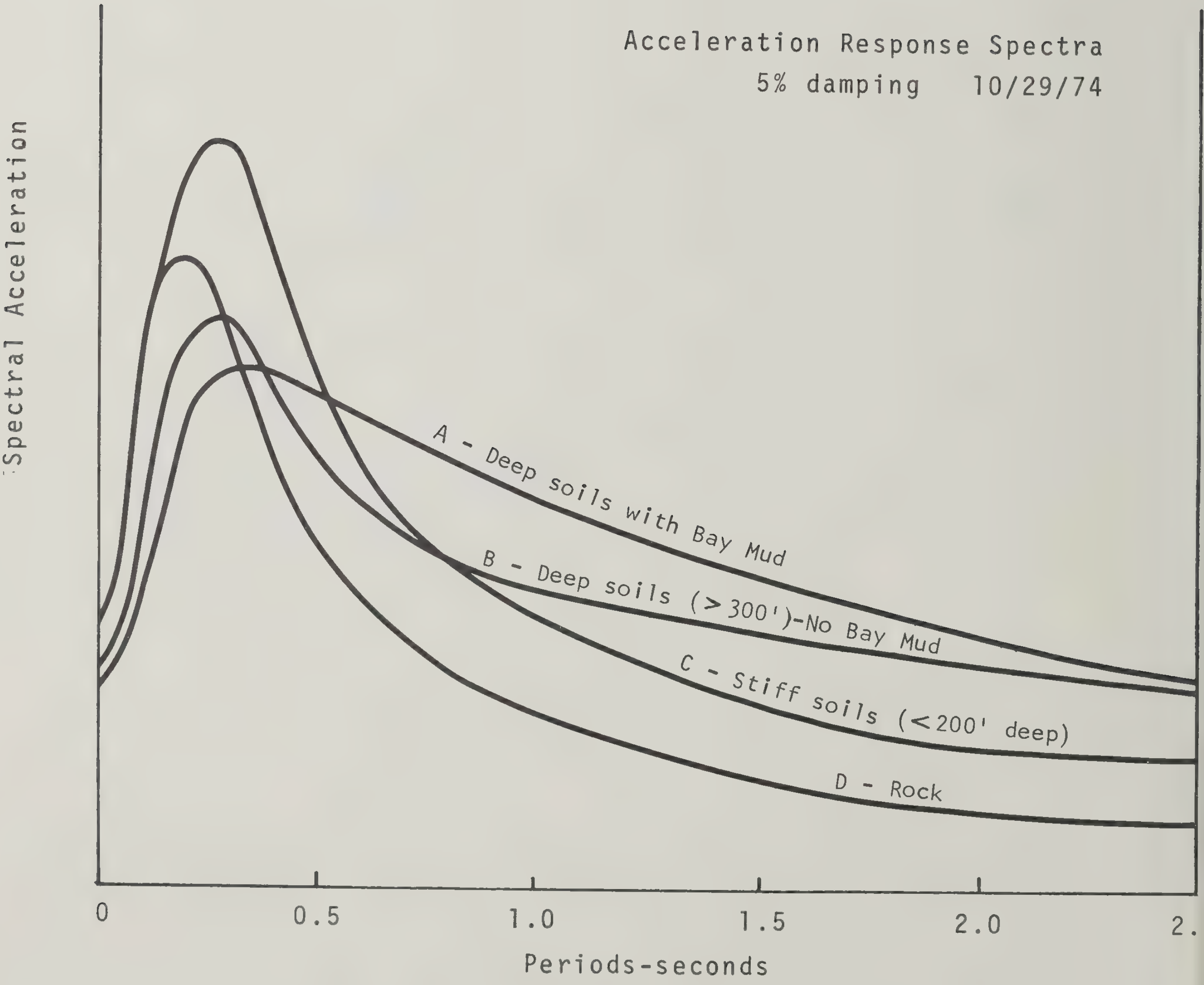
*Prints available at the Transportation Agency.

FIGURE 11



VARIATION OF SOIL-STRUCTURE INTERACTION FACTOR
IN PROPOSED U.S. BUILDING CODE

FIGURE 12



RELATIVE SPECTRA FOR DIFFERENT SITE CONDITIONS
SANTA CLARA COUNTY

SEISMICITY AND STRUCTURAL DESIGN

Land use planning has generally restricted its concern about structures to height, setbacks, lot coverage, and aesthetic evaluation. We now must begin to examine structures for seismic safety. This will require a kind of "overlay" to the traditional land use general plan. The data available at this time is limited and can not be considered definitive. Dr. Bolton Seed has provided us with a "first cut" for defining relative response spectral shapes. That analysis can be used as a general guide for designing structures. Site specific analysis should be required for critical structures.

Structure Types

The type of earthquake damage sustained by various structures has been under continuous study by a number of organizations, one of which is the Pacific Fire Rating Bureau. The purpose of their study has been to set up and revise, when necessary, earthquake insurance rates. An abridged earthquake insurance classification of the Pacific Fire Rating Bureau is shown in Figure 13. The structures are divided into two general categories based on their performance in earthquakes. Category "A" consists of buildings without specific lateral force bracing systems. This category is classified according to construction material used. There are eight classes for earthquake insurance purposes, with Classes I-III having fair lateral force resistance. Category "B" covers buildings with specific lateral force bracing systems usually specifically designed.

The insurance chart should be only used as a guide to the relative safety of the various buildings according to materials of construction. New developments in design and better quality construction have shown that most materials and types of construction can be made earthquake resistant. Therefore, it is more appropriate to compare structures according to material, such as reinforced concrete blocks, as a part of a well-designed earthquake resistant structure as opposed to unreinforced hollow concrete blocks as a part of a poorly constructed building.

Wood — Small wood structures tend to withstand shocks well if the frame is bolted to the foundation. Much of the strength found in these structures depends upon diagonally sheathed wood (or plywood) diaphragms with the edges tied together at the corners. Recent developments could have both a positive and negative influence on the future behavior of wood dwellings. On the positive side, the use of better foundation ties in one-family dwellings should be a strengthening element. On the other side, the trend toward the use of more and larger windows weakens the ability of wood dwellings to resist shocks. The replacement of wood sheathing by plaster or mesh-and-paper backing leads to uncertainties in predicted strength depending on the cement content and nailing of the mesh to the wood studs. Construction of single family homes on slopes and on poor soil will also increase the effect of the possible amount of damage. One-story dwelling units perform better than two-story dwelling units. Older dwelling units do not perform as well as more recently built houses (past twenty years).

FIGURE 13

ABRIDGED EARTHQUAKE INSURANCE CLASSIFICATION
(PACIFIC FIRE RATING BUREAU)

Category	Earthquake Class	Simplified Description of Structures in This Class
"A"	I	Small wood frame structures, as dwellings not over 3000 square feet and not over 3 stories.
Generally without specific lateral force bracing systems	II	One story all steel. Single or multistory steel frame, concrete exterior panel walls, concrete floors and roof--moderate wall openings, otherwise Class V.
	III	Single or multistory concrete frame, concrete walls, floors and roof--moderate walls openings, otherwise Class VI.
	IV	Large area wood frames and other wood frames not falling in Class I.
	V	Single or multistory steel frame, unreinforced masonry exterior panel walls, concrete floors and roofs.
	VI	Single or multistory concrete frame, unreinforced masonry exterior panel walls, concrete floors and roof.
	VII, Reduced Base Rate	Walls of cast-in-place or precast reinforced concrete, reinforced concrete. Reinforcing must be adequate.
	VII	Building with unreinforced brick bearing walls with lime mortar. Certain multistory steel or concrete frame structure with wood floors or unusually poor design features.
	VIII	Bearing walls of unreinforced adobe, hollow clay tile, or unreinforced hollow concrete block.
"B" E.Q. Resistant	"Special Rate"	Buildings which can resist earthquake of 1906 type with minimum to slight property damage.

Note: Unfavorable foundation conditions and/or hazardous roof tends to increase the earthquake hazard greatly.

Small Steel Structures Steel structures, such as gasoline stations, tend to hold up quite well. These light weight metal structures are usually designed to resist wind forces which exceed earthquake design. Mobile homes normally do not suffer substantial damage. The precast concrete pyramid-shaped piers, not normally anchored to the ground, will roll over causing the coach to drop onto the piers which pierce through the floor.

Larger Steel Structures Larger steel buildings, not including tall buildings, may or may not suffer damage depending on the design and strength of the X-bracing rods used in the walls. No significant structural damage was sustained by 30 steel frame high-rise buildings analyzed after the San Fernando earthquake whereas several high-rise reinforced concrete buildings suffered structural damage.

Reinforced Concrete Structures Reinforced concrete structures do not hold up as well as steel frame structures where neither is of earthquake resistant design. There seems to be more opportunity for poor construction with concrete than steel. However, as a class, reinforced concrete structures tend to hold up well if the workmanship is good, especially at the construction joints (the points of connection between concrete pours). Good earthquake resistant design for this material should include low story height and a limited number of wall openings.

Tilt-Up Concrete or Unit Masonry Walls Most new industrial buildings and many shopping center structures have single story tilt-up concrete or unit masonry walls with a plywood roof which acts as a diaphragm (which distributes horizontal and lateral forces). This type of construction showed a 20% loss in the San Fernando earthquake where there was little ground disturbance on site. Comparable data for poured-in-place reinforced concrete walls was not available. When damage to tilt-ups was due directly or indirectly to ground displacement, it was found not to be economically feasible to overcome the problems through construction. However, detailed geologic investigation and careful site planning may avoid the hazardous locations.

Investigations following the San Fernando earthquake revealed that no buildings of this type had totally collapsed in an examination of 61 light industrial buildings, even though the structures were subject to seismic forces greater than the design forces required in the Uniform Building Code. The most critical hazard construction detail is the roof-to-wall ties. Recent construction (1971) in San Fernando was quite inadequate.

Masonry The strength of brick construction depends upon the quality of the brick itself, the mortar, grout, and the use of reinforcing steel. Following the Long Beach earthquake in 1933, plain masonry has been regulated by the building codes to provide better earthquake resistance. As in all construction when the best results are desired, there should be continuous inspection by a competent building inspector. There are several requirements which must be met. A few of these will be mentioned. Just as a cold joint between concrete pours can influence the strength of the structure, the cold joint between brick and mortar must be prepared properly. The brick must contain sufficient moisture to provide a satisfactory bond between the brick and the mortar. Too much moisture will cause the brick to "float." The cement must contain properly graded sand and enough fine-grained

constituents to provide a plastic and cohesive mortar. The amount of lime in the mortar mix will affect its adhesion, workability, and water retention. The importance of good adhesion bond between the mortar and the masonry units has been shown where that bond has failed when subjected to earthquakes. These failures have been caused many times by the use of straight lime mortar or straight cement mortar. Straight lime, or "buttermilk mortar," does not produce calcium carbonate after seasoning, but rather a fragile granular mass. Straight cement mortar shrinks too much and cures irregularly. Unreinforced brick-bearing walls with either of the two types of mortar just mentioned have shown serious damage. More often than not the reason for using hollow concrete blocks is economy. Unfortunately, the economy will often extend to the workmanship. There is nothing wrong with concrete blocks themselves, since they have to be produced in accordance with a set standard; it is the way in which the blocks are used that presents a problem. At times, construction that is classified as reinforced concrete blocks is mislabelled. After the Alaskan earthquake, inspection showed various deficiencies: erratic wire webbing, no reinforcing steel, no grouting, or poorly bonded mortar. The San Fernando earthquake was very destructive to old reinforced masonry buildings, not only in the area of strong shaking but also in adjacent older communities 15 to 25 miles away from the epicenter.

In addition to the possibility of damage to the building itself and the occupants therein, hazards outside the building can cause injury to people in the streets. One of the psychological reactions of human beings upon being subjected to an earthquake is to escape. This usually involves running out into the street, among other places, thus exposing themselves to additional injury. Buildings which are located too close to each other will pound together in a rocking motion during an earthquake. This rocking is usually intensified when the buildings are located on poor foundation soil. Falling debris is responsible for the majority of human injuries. The solid debris is usually made up of non-structural parts of the building such as veneer and window glass and the projecting parts such as gable walls, chimneys (unreinforced), pediments, and parapets. Windows will shatter, hurling glass splinters several feet on both sides, when they are subjected to deflection. Two methods of preventing window distortion are having the glass pane set in soft mastic or putty and having the glass on a frame pivoting in the center. Liquids, as well as solid debris, can be thrown through the air because the liquids in the tanks will respond to earthquake waves, especially long-period waves. The liquid will then slosh back and forth, sometimes damaging the tank tops and moving the entire tank, causing pipe breakage or rupture of the tank. If an elevated water tank is distorted sufficiently, water may be thrown through the air along with parts of the top and sides of the tank. Total collapse of tanks has also occurred. This is particularly a problem when the tank is located on top of a roof and can cause additional damage if it goes through the roof.

Foundations

The footings of any stable building must retain their proper position relative to each other so that they will not spread apart or settle differentially. This is most often achieved by the proper tie or connection on uniform ground (generally compacted prior to construction). When a pile (a column of timber, steel, or concrete driven into the ground to support a load or resist a lateral force) foundation is employed, the connection or foundation tie serves two

purposes: (1) to keep the piles from moving laterally, and (2) to minimize differential settling. Sometimes differential settling which occurred before an earthquake is confused with earthquake damage. Two common methods of achieving connection are the solid mat foundation (a continuous slab of concrete reinforced with steel) and a pile foundation connected by separate struts (bars designed to resist pressure, or compressive stress in the direction of its length). The struts should tie all parts of the foundation in two directions approximately at right angles to each other.

Solid mat and pile foundations are used in large buildings. For the average single family dwelling the foundations seldom require pilings. The most popular foundation is the continuous peripheral footing foundation with pier supports where needed inwardly.

The Uniform Building Code is a set of building code provisions drawn up by a national conference. Each provision must be adopted by the local political unit in order to become law in that locale. The Code requires that each foundation tie (means of interconnection) be capable of carrying by tension and compression a horizontal force equal to ten percent of the design load of the larger pile cap (the beam that rests upon and forms a connection between the head of piles) unless another method can be proved acceptable.

Design

The three earthquake-resistant design methods most often used are (1) shear walls and partitions, (2) bracing, and (3) frame continuity. A shear wall is a "wall designed to resist lateral forces parallel to the wall." The roof and floors act as horizontal girders distributing the lateral forces to the walls and partitions. Naturally, the components must be properly tied together in order to function effectively. Just as poor workmanship and inferior materials can contribute to the weakness of a building in an earthquake, deviation from building plans can bring about the same result. An example of plan deviation showed up after examining the Lockheed plant in Bakersfield following the August 22, 1952 earthquake. The interconnection of roof slabs were three-quarter-inch weld rather than the four-inch weld specified in the plans. Bracing in the single family home may consist of any of the following methods: double top plate, blocking between the studs; studs at sixteen inch intervals; sheet metal tension bracing straps; and wood compression bracing.

The method of frame continuity is described under the "space frame" definition in the Uniform Building Code as follows:

> . . . a three dimensioned structural system composed of interconnected members, other than shear or bearing walls, laterally supported so as to function as a complete self-contained unit with or without the aid of horizontal diaphragms or floor bracing systems.

A simpler definition might be to think of a space frame as a box girder or box system. This principle is used in the prefabricated buildings in the USSR with the ready-made room blocks which are securely tied together.

It is easier to achieve equal and symmetrical bracing of walls and partitions if the building is square or rectangular in shape. A complex-shaped building can be divided up into rectangular sections, that is, box girders.

Though the question of the relative safety of rigid and flexible design is not resolved, the consensus of opinion favors rigid design at this time. This opinion is based on two factors: (1) there are few well-designed flexible structures which have been tested by an earthquake; and (2) the rates set by insurance firms favor rigid construction, which is a reflection of structural engineers' faith in rigid design. Both theories originated in Japan. Dr. Riki Sano advocated the rigid structure to provide stiffness to withstand the lateral force of earthquake tremors. Flexible structures, as proposed by Dr. Kenzabura Majima, would not suffer as much from seismic waves as would rigid structures. Basically, the rigid design is based on the measure of strength; and the flexible, on the measure of deformation. The flexible design idea most often cited is that of an Italian engineer who proposed putting a frame of rigid design on rollers in large spherical joints. This approach is called the "flexible link," applying the principle of the seismograph with a relatively acceleration-free mass, to a building. The various ideas using the "flexible link" method neglect the problem of utility connections into the building for gas, electricity, water, sewer, and telephones.

The insurance firms favor rigid construction based on the past behavior of buildings without adequate earthquake bracing, particularly tall buildings. Most buildings over ten stories in height cannot be designed for high rigidity and can be considered somewhat flexible. Tall buildings will often survive an earthquake with no structural (frame) damage, but with a great deal of non-structural damage (partitions, masonry, filler walls, ceilings, and veneer). This kind of non-structural damage can represent fifty percent of the total value of the building. If non-structural elements are brittle and story distortion has not been anticipated in the design, occupants can be harmed by glass and plastic breakage. All parts of the structure should move as one unit, otherwise the non-structural elements should be considered expendable. Building occupants are subject to the additional hazard of machinery, filing cabinets, desks, etc. that may become mobile during an earthquake.

An economically realistic compromise has been suggested on a "plateau" basis. This concept uses the rigid elements as indicated in the Code which would provide for earthquakes of moderate intensities about every fifteen years. A "reserve ductile" frame would then be available for severe earthquakes of about fifty year frequency to allow controlled flexibility, energy absorption, and hold the building together even though the non-structural elements might fail.

When the natural period of vibration of the building coincides with the natural period of the ground, the building will resonate. Tall buildings are particularly susceptible to long period ground motion from severe tremors with epicenters seventy to ninety miles from the structures. The long period ground motion, which is a "long slow rolling motion," will set tall buildings in motion, causing them to sway. The duration of the vibration will increase when the structure is located on poor foundation soil and there is a high level of water content in the soil. As the swaying continues a "whip-effect" may develop which causes the upper stories to fail. This phenomenon can cause anything from panic to actual casualties.

Ground motion, whether long period or short period (rapid shaking or large amplitude), feeds energy into a structure. This energy is dispersed in three ways: (1) "stored in the structure in the form of kinetic energy of motion of the mass," (2) "stored in the form of strain energy of deformation of the structural member," and (3) through damping (slowing down a motion due to resistance as by friction or a similar cause). If the amount of energy feeding into the structure is more than can be absorbed in elastic strain energy, it will cause some part(s) of the structure to deform or possibly fail. Some authorities feel that buildings should be designed to absorb large amounts of energy through harmless distortion in joint details either by friction or looseness in the joint ("floating" construction). Damping serves to disperse vibrational energy as well as counteracting the tendency of a building to respond to the long period ground waves.

There are five types of damping:

(1) air damping due to motion of the structure in air (least important type); (2) material damping due to internal elastic and plastic deformation of the structural material components; (3) rubbing due to distortional interaction of the structure's foundation with its surrounding ground; (4) rubbing due to distortional interaction of the various structural elements; and (5) non-returnable energy radiation from the structure's foundation back into its surrounding ground (most important source of damping).

Sometimes poorly designed buildings will survive an earthquake because of the damping which takes place in its loose joints. Non-structural damage, that is, internal cracking and rubbing of surfaces of plastic, masonry filler walls, etc., is an example of damping which will often allow a building to survive its first earthquake. Since damage is cumulative if it is not found and completely repaired, the building may not survive another shock. "Paint and plaster" repair do no more than mask a potential danger.

Local Conditions

Strict enforcement of the Housing Code and Dangerous Building Code would have a socio-economic impact on the existing population. Many local jurisdictions wait until a house is vacant before certifying that it is unsafe. The critical shortage of low and moderate income housing would probably be intensified with a vigorous enforcement of the Housing Code. Enforcement of the Dangerous Building Code is often a prolonged procedure involving litigation. The other side of the coin is the potential public liability after a disaster if codes are not enforced. The U. S. Department of Labor Office of Occupational Safety and Health Administration limits its interests to building contents rather than the structure itself. Enforcement of the Field Act has caused the abandonment and/or demolition of many school buildings. The cost of remedial work generally amounts to a relatively large percentage of the total value of the building. Given that choice, most school districts choose not to do remedial work.

Ideally, we should have a complete analysis of the seismic safety condition of all structures in Santa Clara County. Since this is not economically feasible, critical structures should receive high priority for inspection and evaluation.

Seismicity and Structural Design Recommendations

1. A long range hazardous building inspection program should be planned with the critical structures given high priority.

2. Critical structures should be designed to resist minor earthquakes without damage; resist moderate earthquakes without structural damage, but with some non-structural damage; and resist major earthquakes of the intensity or severity of the strongest experienced in California without collapse, but with some structural as well as non-structural damage.

3. Critical structures should be designed using the "Recommended Lateral Force Requirements" prepared by the Structural Engineers Association of California.

4. Residents of low and moderate income housing suspected of being unsafe should receive high priority for subsidized housing.

It is relatively easy to make recommendations to resolve earthquake hazards alone. The difficult task is resolving the related economic and social costs involved in those decisions.

One approach is acceptable risk; the State defines it as "the level of risk below which no specific action by local government is deemed necessary, other than making the risk known." Figure 14 is the State's suggested scale of Acceptable Risks. While the public is becoming increasingly aware of seismic hazards, detailed information is not often available even if an astute consumer seeks it. As an example, State Real Estate reports that note some geologic hazards are made known just to the first buyer within a major subdivision. Title reports and subdivision maps do not normally report such hazards at this time. The "Scale of Acceptable Risks" has been developed on the basis of which structures are critical after a disaster and level of occupancy. Critical structures are those structures 1) needed after a disaster: emergency communications, fire stations, police stations, hospitals, bridges, and overpasses; 2) whose continued functioning is critical: major power lines and stations, water lines, and other utilities; 3) whose failure might be catastrophic: large dams. Another dimension is that of involuntary occupancy such as in jails, nursing homes and schools, and voluntary occupancy such as in theaters and churches.

An unacceptable risk is the "level of risk above which specific action by government is deemed necessary to protect life and property." An avoidable risk is a "risk not necessary to take because the individual or public goals can be achieved at the same or less total "cost" by other means without taking the risk."

Another means of evaluation is to cost out the possible property damage and loss of life in subareas. This methodology has been used by the City of Mountain View. Subarea analysis can help give priority to high hazard areas. This can lead to higher standards, such as requiring a geologic investigation in certain areas or for certain critical structures, along with special design and construction standards. Revisions in zoning and the general plan may also be appropriate for certain subareas.

Critical structures in high hazard areas should receive high priority for building inspection for hazards if they were not built with specific standards. Subarea analysis can also be useful for disaster planning, since the more hazardous areas and structures can be expected to suffer more in an earthquake. After a disaster, the community is dependent upon public loans and grants as well as private investment monies. Public and private cost as a result of earthquake damage is a tremendous burden to both parties.

While post-earthquake rehabilitation loans may be available, they may not be feasible if diminished earnings which often follow an earthquake negate repaying the loan. Commercial loan sources may impose a high collateral, high interest rates, and ceilings on borrowing capacity. One solution to ease the public costs associated with post-earthquake aid is earthquake insurance. Most homeowners do not carry such insurance. The average cost of earthquake insurance in Santa Clara County for a single family wood frame home valued at $30,000 is $42-$60 per year.

With either approach a post-earthquake land use contingency plan should be ready. Traditionally, federal monies have been made available to restore essential

Figure 14

A SCALE OF ACCEPTABLE RISKS

Level of Acceptable Risk	Kinds of Structures	Extra Project Cost Probably Required to Reduce Risk to An Acceptable Level
1. Extremely low [1]	Structures whose continued functioning is critical, or whose failure might be catastrophic: nuclear reactors, large dams, power intertie systems, plants manufacturing or storing explosives or toxic materials	No set percentage (whatever is required for maximum attainable safety)
2. Slightly higher than under level 1[1]	Structures whose use is critically needed after a disaster: important utility centers; hospitals; fire, police, and emergency communication facilities; fire stations; and critical transportation elements such as bridges and overpasses; also smaller dams	5 to 25 percent of project cost [2]
3. Lowest possible risk to occupants of the structure [3]	Structures of high occupancy, or whose use after a disaster would be particularly convenient: schools, churches, theaters, large hotels, and other high-rise buildings housing large numbers of people, other places normally attracting large concentrations of people, civic buildings such as fire stations, secondary utility structures, extremely large commercial enterprises, most roads, alternative or noncritical bridges and overpasses.	5 to 15 percent of project cost [4]
4. An "ordinary" level of risk to occupants of the structure [3, 5]	The vast majority of structures: most commercial and industrial buildings, small hotels and apartment buildings, and single family residences.	1 to 2 percent of project cost, in most cases (2 to 10 percent of project cost in a minority of cases)[4]

1. Failure of a single structure may affect substantial populations.

2. These additional percentages are based on the assumption that the base cost is the total cost of the building or other facility when ready for occupancy. In addition, it is assumed that the structure would have been designed and built in accordance with current California practice. Moreover, the estimated additional cost presumes that structures in this acceptable-risk category are to embody sufficient safety to remain functional following an earthquake.

3. Failure of a single structure would affect primarily only the occupants.

4. These additional percentages are based on the assumption that the base cost is the total cost of the building or facility when ready for occupancy. In addition, it is assumed that the structures would have been designed and built in accordance with current California practice. Moreover the estimated additional cost presumes that structures in this acceptable-risk category are to be sufficiently safe to give reasonable assurance of preventing injury or loss of life during and following an earthquake, but otherwise not necessarily to remain functional.

5. "Ordinary risk": Resist minor earthquakes without damage; resist moderate earthquakes without structural damage, but with some non-structural damage; resist major earthquakes of the intensity or severity of the strongest experienced in California, without collapse, but with some structural as well as non-structural damage. In most structures, it is expected that structural damage, even in a major earthquake, could be limited to repairable damage. (Structural Engineers Association of California).

Source: Meeting the Earthquake Challenge, Joint Committee on Seismic Safety of the California Legislature, January 1974, p. 9.

public facilities, repairs, and restore small business and loans to private property owners. There is a coordinated aid program under HUD and FDAA; but there is no effective effort to change the pattern of land use. Normally the same mistakes are rebuilt without a post-earthquake contingency plan to guide land use decisions and direct the flow of loans and grants to make the plan a reality. Public and private losses can be minimized by sound land use decisions in yet undeveloped areas.

RISK EVALUATION AND DISCLOSURE RECOMMENDATIONS

1. Known or potential geologic, fire, and flood hazards should be reported as part of every real estate transaction, as well as recordation on documents to be reported for building permits, parcels, subdivisions, and land development reports. Mitigation of hazards should be noted in the same manner.

2. Private and public agencies involved in land development such as lending agencies, title companies, real estate brokers, appraisers, engineers, and contractors should be provided with hazard data as soon as it becomes available.

3. A post-earthquake land use contingency plan should be developed and made available to all federal, State, and local agencies normally involved in post-disaster rehabilitation.

RELATIONSHIP TO OTHER ELEMENTS OF THE GENERAL PLAN

One of the most effective means of testing the potential for seismic recommendations ever being implemented is to examine the relationship between them and other elements of the General Plan: land use, housing, circulation, open space, safety, noise, public facilities, community service, conservation, and scenic highways. The examination of each element should include the following questions:

1) What are the existing conditions?

   a) land use
   b) structures (hazardous condition, critical use, etc.)
   c) ground conditions relating to static and seismic behavior

2) What could happen under siesmic conditions as applied to the above?

3) How can possible loss of life and property be minimized?

   a) with today's conditions
   b) by modifying proposed land uses, building codes, and adopting geologic ordinances

4) How can we apply the risk factors?

   a) what types of risks are involved?
   b) what kinds of costs are involved (social, economic, private, and public)?

5) What recommendations can be made based on 3 and 4?

Figure 15. **Lifeline Regulation and Earthquake Concerns***

Lifeline	Design and operating agency.	Regulating Authority.	Enforced Codes or Standards.	Professional or Industry Organizations.	Special Vulnerability.	Urgent Investigation Needs.
			ENERGY			
Electricity	Privately owned utility.	PUC, FPC	GO 95, 128, 131 PU Code	ASCE, IEEE, ANS, AEC, ANSI	Distributing stations. Power Plants. Dams	Electrical equipment. Transformers.
	Municipal Department.	Municipality	Department			
Gas	Privately owned utility.	PUC, DOT	GO 112C PU Code, DOT pipeline standards.	WOGA, ASCE, ASME	Transmission lines. Reservoirs.	Buried pipes.
Liquid Fuel	Oil company.	Division of Industrial Safety. State Safety Board.	DOT pipeline standards SSB pending.	WOGA, ASCE, ASME	Transmission lines. Tanks.	Buried pipes. Tanks.
			WATER			
Potable Water	Municipal department.	Municipality	Department	ASCE, AWWA	Dams. Aqueducts.	Old dams. Buried pipes. Surface pipes. Tanks. Underground structures.
	Privately owned utility.	PUC	GO 103 PU Code			
	Water districts	District	District			
	California DWR	DWR	DWR			
	USBR	USBR	USBR			
	Corps of Eng.	Corps of Eng.	Corps of Eng.			
Flood water	County district.	County supervisors.	District	ASCE	Dams. Main channels.	Fault crossings.
	Corps of Eng.	Corps of Eng.	Corps of Eng.			
	Municipal Department.	Municipality	Department			
Sewage and Solid Waste	County district.	County supervisors.	District	ASCE, ASWA	Collectors. Treatment plants.	Buried pipes. Landfills.
	Municipal Department.	Municipality	Department			
Fire water	Municipal Department.	Municipality	Department	ASCE	Tanks. Mains.	

*From Earthquakes and City Lifelines

Figure 16. **Lifeline Regulation and Earthquake Concerns (Continued)**

			COMMUNICATION			
Telephone, Telegraph, Cable TV	Privately owned utility.	PUC, FCC	PU Code	IEEE, ASCE	Distributing stations.	Telephone equipment.
Radio and Television	Broadcast station or network.	FCC		IEEE, ASCE	Transmitters. Transmission towers.	Transmitter equipment.
			TRANSPORTATION			
Railway	Railroad co.	ICC, PUC	AREA Code.	AREA, ASCE	Bridges. Tunnels. Fills.	Bridges
Harbor	Corps of Eng.	Corps of Eng.	Corps of Eng.	ASCE	Quay walls. Hydraulic fills.	Filled land.
	Municipal Department.	Municipality	Department			
Airport	Municipal Department.	Municipality	Department	ASCE	Runways. Control towers.	Settlement.
	FAA	FAA	FAA			
Highway	Division of Highways.	Division of Highways	FHA Division of Highways.	AASHO, ASCE	Bridges. Landslides. Fills.	Bridge design. Existing bridges.
	Municipal Department.	Municipality	Department			
			GENERAL			
Dams	All but Federal	DWR	DWR guidelines	ASCE	Cracking.	Design loads.
Buildings	All but State	Municipality	Building code.	SEAOC		Site effects.
Reactors	All	AEC and PUC	AEC	ASCE, ANS	Loss of coolant.	Criteria.

EXPLANATION OF ABBREVIATIONS

AASHO	American Association of State Highway Officials
AEC	Atomic Energy Commission (Federal)
ANS	American Nuclear Society
ANSI	American National Standards Institute
AREA	American Railroad Engineering Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASWA	American Sewage Works Association
AWWA	American Water Works Association
DOT	Department of Transportation (Federal)
DWR	Department of Water Resources (State)
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
FHA	Federal Housing Authority
FPC	Federal Power Commission
GO	General Order of PUC
ICC	Interstate Commerce Commission (Federal)
IEEE	Institute of Electrical and Electronic Engineers
PUC	Public Utilities Commission (State)
PU Code	Public Utility Code (State)
SEAOC	Structural Engineers Association of California
SSB	State Safety Board of Division of Industrial Safety
USBR	United States Bureau of Reclamation (Federal)
WOGA	Western Oil and Gas Association

PUBLIC AND QUASI-PUBLIC FACILITIES AND COMMUNITY SERVICES

Everyone living in a metropolitan area is dependent upon public facilities. The degree to which that dependency exists varies widely. For transportation, we need freeways, roads, bridges, railroads, and airports; for energy, electricity, gas and liquid fuel; for communication, telephone, radio, TV, and the written word; for life functions, water and sanitation facilities; and for health and safety, hospitals, fire, police, and flood control. A relatively new professional field has emerged, i.e., lifeline engineering. This new field deals with the possible failure of any of the "lifelines" that might bring damage or disaster to a city by stopping the flow of energy, people, goods, water, wastes, or information.

The Joint Seismic Safety Committee report, The San Fernando Earthquake of 1971 and Public Policy, includes a chapter entitled "Earthquakes and City Lifelines" from which the following statement is extracted:

> "As of February 8, 1971, the day before the San Fernando earthquake, there was a certain level of earthquake engineering practice relative to city lifelines. This level was grossly below the corresponding state of the art relative to buildings, with certain exceptions. The reasons for this included a lack of research, a diffusion of professional responsibility, and the variety and complexity of the machines, networks, transmission lines, structures, pipelines, and underground conditions."

The report referred to above was prepared by the Earthquake Engineering Research Institute (EERI) and the National Oceanic and Atmospheric Administration (NOAA). Its purpose is to assess the problem of earthquake safety of city lifelines using the San Fernando earthquake as the case study, the pre-1971 state-of-the-art and to recommend appropriate action.

Interviews with the staffs of the utilities and the California Public Utilities Commission (PUC) was summarized in figures 15 and 16 from the above report.

The information is particularly helpful in understanding the variety of agencies involved having both operational or regulatory functions. Control over seismic safety of lifelines is largely exercised by the respective design and operating agencies, both public and private. There is a need to elevate the professional engineering state-of-the-art by both research in design criteria, and training of practicing and student engineers.

> "Given a significant higher state of the art lifeline earthquake engineering, it would take perhaps 100 years for the existing facilities to be brought up to the new standards through normal obsolescence and replacement. This would be too long to wait. The problem would seem to be resolvable on the basis of good communication between the utilities and an educated public, in which the latter could express the risk they would be willing to accept by reacting to various rate-level proposals by the former."

One of the first steps toward resolving the problem is the evaluation of existing lifeline facilities for seismic fesistance. The next is to rectify the glaring earthquake hazards. This Seismic Element staff has sent initial inquiries to the California Division of Highways, Pacific Gas and

Electric Company, and Southern Pacific Pipelines, owner of most of the petroleum storage tanks along the Coyote Creek. The State has required that the Santa Clara Valley Water District report on the safety of its dams (see "Earthquake Related Flooding"). The geologic and engineering data in the Seismic Element should assist in a future evaluation program of lifeline facilities. There is no central "clearing house" for all lifeline information, evaluation, or establishing priorities to resolve existing seismic hazards. Every operating agency must be contacted individually. Some of the questions that need to be part of the evaluation program are:

1. How vulnerable to short and long term disruption are the lifelines?

2. Does each lifeline have sufficient repair equipment to shorten recovery time or standby equipment to supply needs over an extended recovery time?

3. Are present design standards sufficient to meet probable seismic damage?

4. How did the lifelines perform in past earthquakes, here and in similar areas?

5. Will the lifeline alleviate the effects of an earthquake or will parts of it become or precipitate a disaster?

PUBLIC AND QUASI-PUBLIC FACILITIES AND COMMUNITY SERVICES RECOMMENDATIONS

1. All agencies responsible for operating "lifelines" in Santa Clara County should: a) make an evaluation of the seismic resistance of their existing and proposed facilities including access to facilities in order to repair damage, b) report the results of that evaluation to affected jurisdictions, and c) describe how they plan to improve the conditions. The evaluation should deal with the entire County as well as each potentially isolatable area.

2. All agencies responsible for operating "lifelines" in Santa Clara County should encourage the upgrading of the professional level of education related to earthquake engineering by education of present staff and hiring or having on retainer the necessary expertise to evaluate and solve seismic problems as related to their agency functions.

3. Establish a Santa Clara County "clearing house" for lifeline information, evaluation, and plans in order to help set priorities to resolve existing local earthquake hazards.

4. Duplicate records (perhaps on microfilm) of utility systems and other lifeline components should be stored in emergency operations centers for continuing operations and repair of vital services in the event of a disaster.

5. Emergency operations center structures should be evaluated for seismic vulnerability and should be designed and constructed to assure the continuity of vital services following a damaging earthquake.

6. Locational studies for future hospital, outpatient, and emergency medical facilities should weigh the needs within each potentially isolatable area.

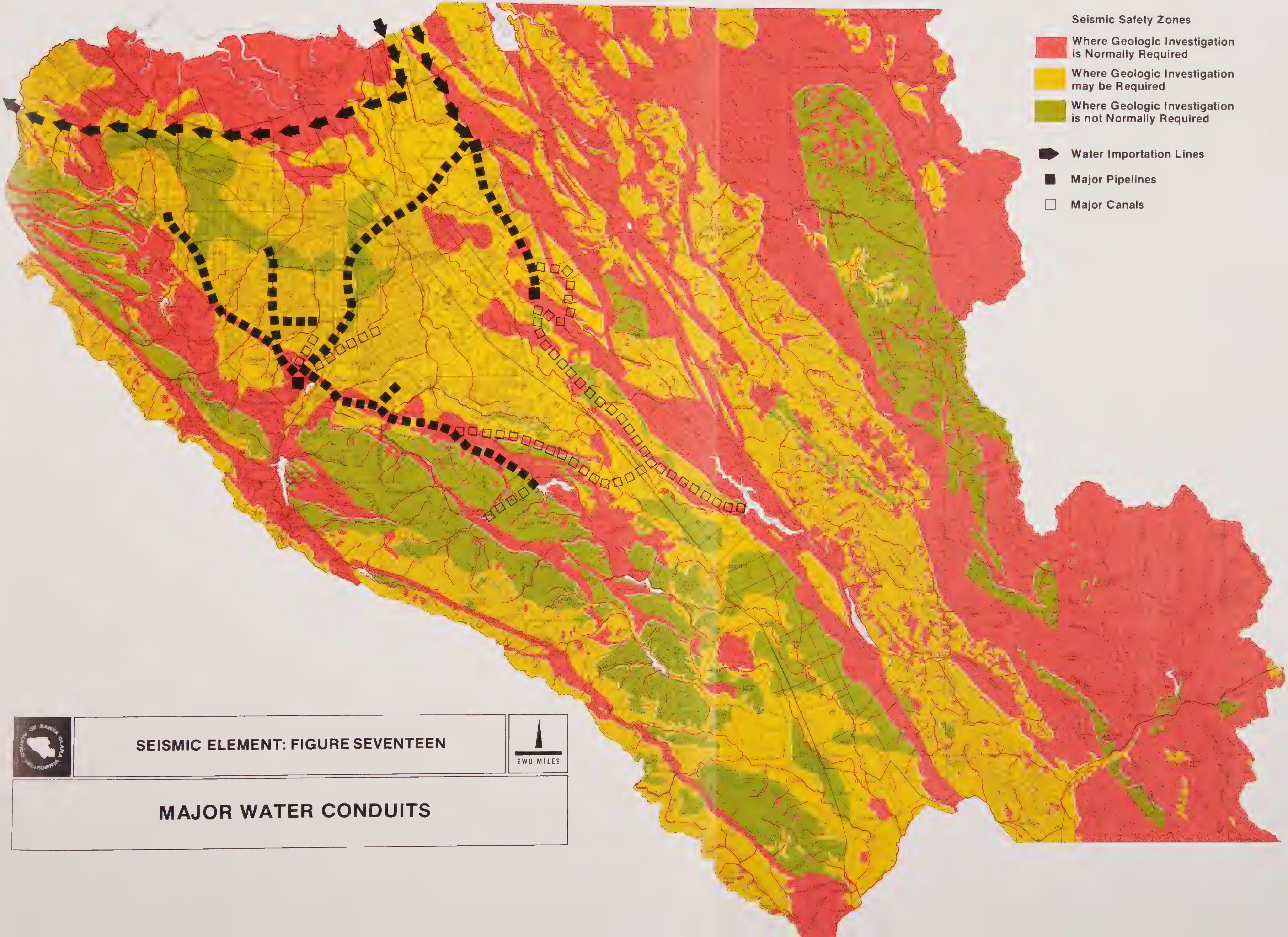
7. Each household should make provisions for storing at least $3\frac{1}{2}$ gallons of drinking water for each family member.

8. Each potentially isolatable geographic area should develop a self-contained water supply by storage facilities, dry wells, percolation ponds, effluent reclamation, and/or other feasible means.

Public Utilities

Earthquake threats to public health and welfare are more indirect than direct. This is particularly applicable to utilities. There are often unavoidable situations where utilities must cross earthquake fault lines or be located in structurally poor ground such as potential landslide areas or liquefiable sands. While we can make certain assumptions about where lines might be disrupted due to ground conditions, the exact locations and extent of damage to any utility would depend on the magnitude and location of the earthquake.

The operation of public utility systems after a disaster has three levels of urgency: first--firefighting, operation of emergency facilities and services, and fire as a direct result of gas line rupture; second--drinking water, sanitation, heating, bathing, and laundry facilities; and third--social and economic recovery of the community.



SEISMIC ELEMENT: FIGURE SEVENTEEN

MAJOR WATER CONDUITS

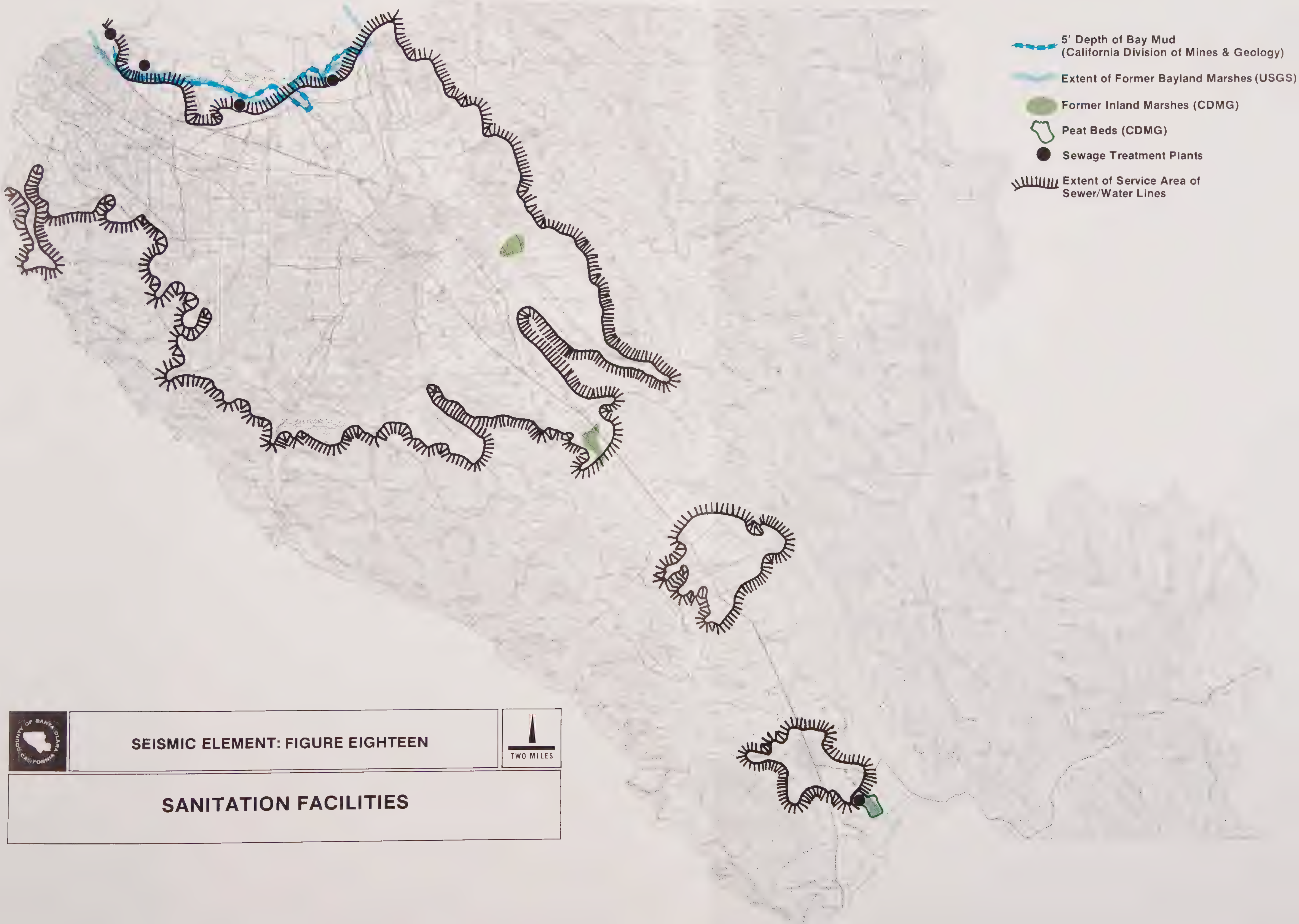
Fresh Water Supply Pipelines and Aqueducts An extensive water distribution system exists throughout the urban portion of the County. This system is augmented by thousands of wells, both in the urban and rural area (figure 17 shows the major water conduits and the Seismic Element zones). Failure within the water system can be minimized but not eliminated. Underground tunnels in San Fernando were damaged. Our major aqueducts, Hetch Hetchy and South Bay Aqueduct, cross the Hayward fault. It was recommended that open channels be used where water must cross the fault in order to facilitate repairs. It took eleven days after the San Fernando earthquake to complete a temporary aboveground water system. Portable irrigation pipes can be used. Wells require either electricity or gas-powered units to operate. Additionally, an unknown number of well casings will be damaged by a large earthquake; sliding joints or casings are recommended. Portable power units (available in each isolatable area) to pump well water would be one means of providing water. Water trucks provided a mobile source of water in San Fernando after the roads were open for travel. The Santa Clara Valley Water District has a portable chlorinating truck which has an intake pump which draws in raw water from the creek and discharges chlorinated water for drinking. The roads would have to be cleared for that method also.

Sanitation Disruption of sewage systems after an earthquake will be dependent not only upon the location and magnitude of the earthquake and specific site conditions, but also upon the condition of the sewer lines and the ability of the water quality plant to process the sewage if it gets that far. Clay tile sewer lines were shattered in fault zones and ground cracking in San Fernando. The condition of the sewer lines is quite varied since there are some very old lines still in use as well as more recent installations. All of the water quality plants are located in the Baylands either on former marshland or very close to those lands. In the 1906 earthquake the San Francisco area had considerable ground motion in the filled-in tidal areas, marshlands, and swamps where settlement was five feet and lateral movement was six feet. Sewers were destroyed. Similarly, records for Santa Clara County showed a great deal of ground motion in the Baylands not far from the sewage treatment plant. Figure 18 shows the sewage treatment plant, the extent of former marshlands, and area served by sewer and/or water lines. The NOAA report on Earthquake Losses in the San Francisco Bay Area assumed that two-thirds of the raw sewage produced in three major counties (including Santa Clara County) will be discharged into San Francisco Bay to bypass inoperative sewage plants. Some wells were contaminated by sewer line leakage in San Fernando. It was recommended that all septic tanks and cesspools close to wells should be abandoned, cleaned, and backfilled to prevent contamination. As long as piped water is not available, the sewage line will not be used much anyway. Portable toilets were placed in most neighborhoods in San Fernando.

Gas and Electricity Electrical power was out for days in some areas of San Fernando. Permament differential ground movement caused extensive damage to buried gas transmission pipes. There is no doubt that piping can be economically designed to resist such movements. The major gas and electric lines are shown on Figure 19 superimposed on the Seismic Element Zones.

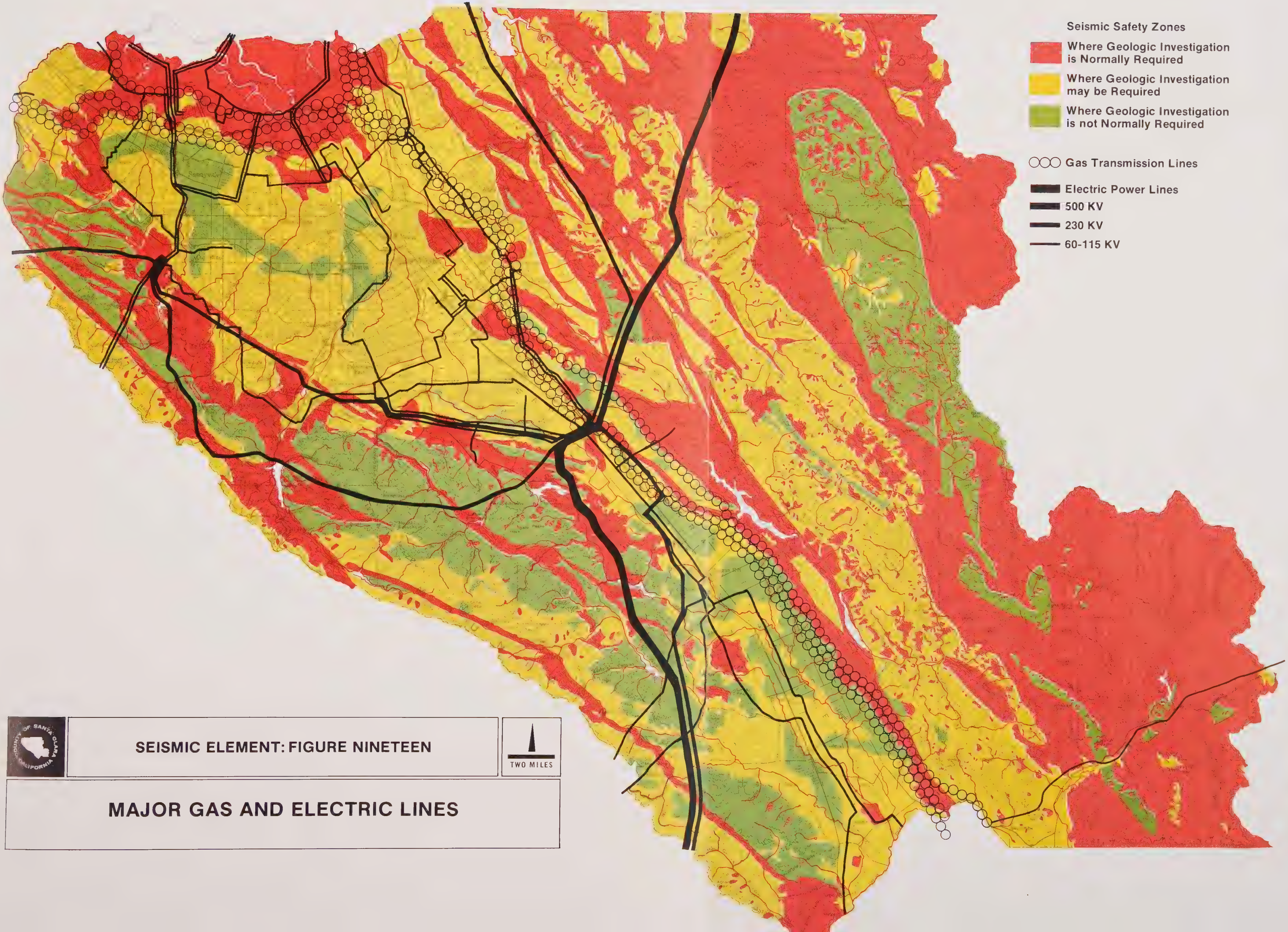
Fuel Storage Tanks and Pipelines

These structures are not public utilities but their behavior is related to other pipelines. Most large storage units for flammable and toxic liquids are rigidly controlled in terms of structure but geologic investigation for seismic conditions has not been the rule. Most storage is underground. There are, however, large gasoline storage tanks along the Coyote Creek. The sides



SEISMIC ELEMENT: FIGURE EIGHTEEN

SANITATION FACILITIES



SEISMIC ELEMENT: FIGURE NINETEEN

MAJOR GAS AND ELECTRIC LINES

of the creek for several hundred feet on both sides may be subject to ground failure based on general geologic studies and the history of the 1906 earthquake in that area. If the storage tanks ruptured under these conditions and the gas ignited, the fire could be expected to travel down the creek to the Bay.

The following questions and answers are a part of the contents and response to a letter sent to Southern Pacific Pipeline, owner of most of the gasoline storage tanks along the Coyote approximately 1500 feet south of Trimble Road:

1. Q. Did your soils reports on pipelines and storage tanks cover geologic conditions, especially the potential for ground failure due to shallow liquefaction under seismic conditions?

   A. Soils reports covering the pipelines and storage tanks at SPPL's San Jose Terminal did not cover the area of potential for ground failure due to shallow liquefaction under siesmic conditions.

2. Q. Are there automatic shutoff valves on your pipelines from the north and connecting to Shell Oil?

   A. An automatic shutoff valve exists on the line from Concord to San Jose at its crossing with the Hayward fault. The line connecting SPPL's and Shell Oil's San Jose Terminals is equipped with manual valves; however, SPPL's terminal is manned 24-hours per day allowing immediate valve closure in the case of an emergency.

3. Q. If "one" and "two" are not positive responses, what plans do you have to ameliorate the situation and what is your timing?

   A. SPPL plans to participate in the petroleum industry's present efforts to further study the reaction of liquid storage tanks to seismic loads. These studies would likely be undertaken at the University of California Earthquake Simulator Laboratory in Berkeley.

4. Q. How many storage tanks do you have and what do they store?

   A. At SPPL's San Jose Terminal there are twenty-nine storage tanks. Twenty-two of these are in gasoline service, five in diesel service, and two in utility service.

Circulation

At this point in time the great bulk of the population is dependent upon cars and buses on roadways and freeways as the most available form of transportation. Damage to roadways in the 1906 earthquake is cited from the Carnegie Institute report, The California Earthquake of April 18, 1906:

> Page 280 . . . (Milpitas) "Of the two bridges over the Coyote Creek, the northern one suffered some damage by displacement of end supports. It was unsafe to travel over at the time of the visit. The southern bridge was found intact, the end supports showing signs of but small movement . . . .
>
> Page 281 . . . (Alviso to Milpitas) "From 1,500 to 2,000 feet west of the bridge over Coyote Creek, cracks cross the road in front of the Boot ranch house, and several of them occur in the road leading to

that house. (Plate 140 B) Some of these cracks are about 6 inches wide and have a general bearing of N.43° W. Immediately after the earthquake, water flowed some of them and brought up sand, which was heapt up about 6 inches high. The water ceased to flow after the second day . . . .

. . . People living near Coyote Creek state that the water rose between 2 and 3 feet immediately after the earthquake; and up to April 26 the water in this stream had not returned to its normal level. At the bridge over Coyote Creek, on the Alviso-Milpitas road, the concrete abutments were thrust inward each other about three feet . . . .

. . . In the road running northward along the west side of Coyote Creek from the bridges, many large cracks opened. Five hundred feet north of the bridge the cracks were 2.5 feet wide and 3 feet deep when the place was visited April 26. Farther north the cracks were very abundant, mostly parallel with the road and some were 4 feet deep and 3 feet wide. A quarter of a mile north of the bridge, the whole road was shoved eastward into the channel of the creek, and with it a large number of willows and cottonwood trees that grew along the banks. Just south of this place the road was broken up badly for a distance of 300 feet. One of the largest cracks in the road was 5 feet wide, 6 feet deep, and more than 100 feet in length. The bearing of the fissure at this place was N. 23° W. For the most part the principle features were approximately parallel with Coyote Creek . . . ."

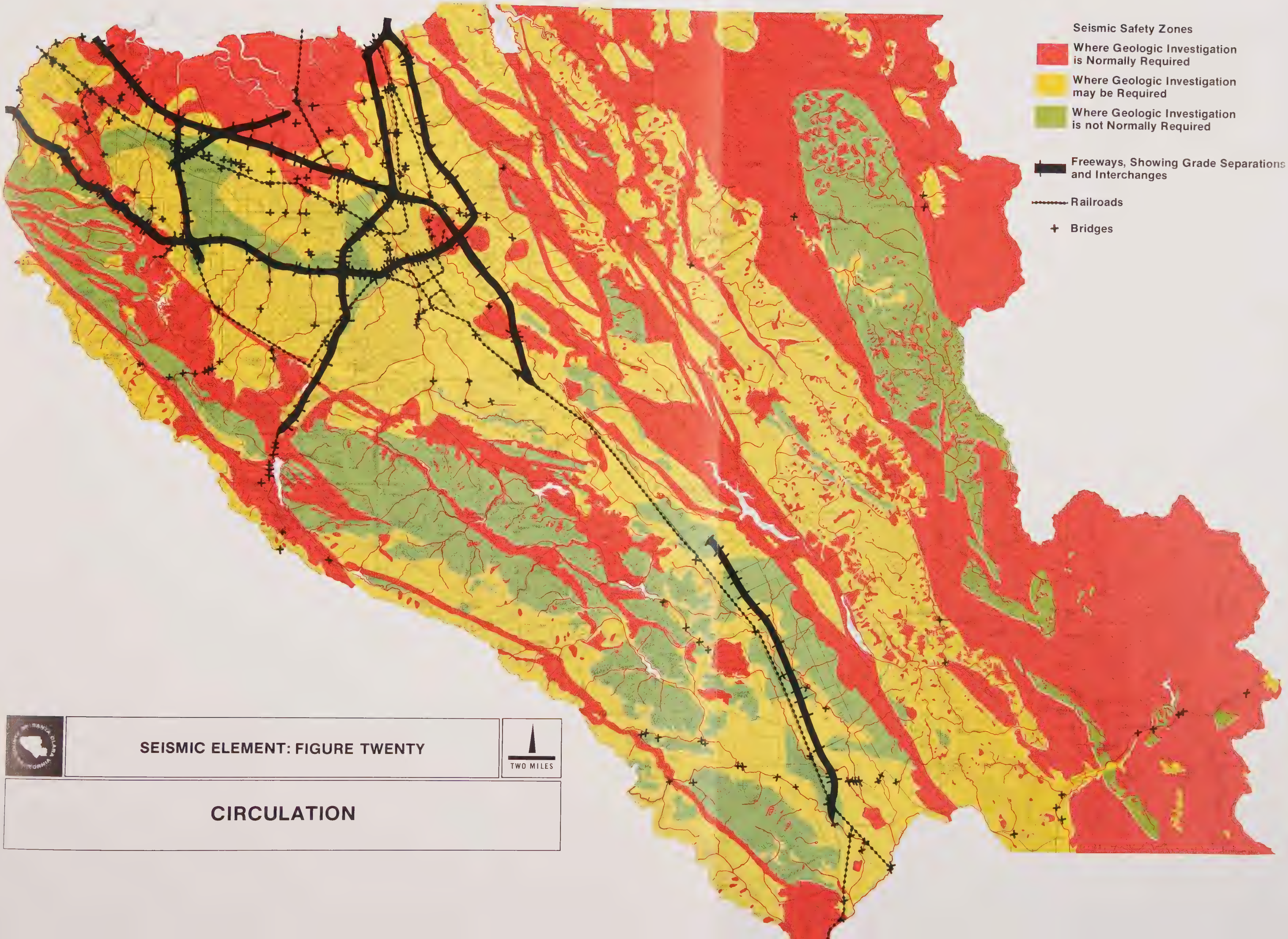
The San Fernando earthquake caused closure of several mountain roads because of landslides, fill settlement and fault breaks through the pavement. Fill settlement at bridge approaches caused a step in the road. Railroad damage was confined to bent rails and damage fills near landslides. A collapsed highway bridge blocked the railroad in one location. Glass breakage occurred at control towers of two airports. Loss of commercial (airport and auxiliary) electrical power blacked out terminal buildings, and prevented pumping of aircraft fuel.

Damage to roadways, freeways, railroads and bridges (includes overpasses) will be a function of poor ground conditions (including landslide and fault movements) and structural failure. An assessment of the railroad and local roadways is not available at this time. The State Division of Highways has been kind enough to answer our inquiry regarding local freeways and bridges (overpasses).

The State's evaluation of sixty major overpasses stated that bridges with structural steel girders on narrow bearing seats, which are subject to loss of spans, were considered to be relatively susceptible to damage from a major earthquake. The more recently constructed reinforced concrete bridges are considered to have somewhat higher earthquake resistance. Figure 20 shows the location of major roadways, separated grade crossings, bridges and Seismic Element Zones.

Circulation Recommendations:

1. Existing transportation routes, facilities and structures should be evaluated for vulnerability.


Seismic Safety Zones
Where Geologic Investigation is Normally Required
Where Geologic Investigation may be Required
Where Geologic Investigation is not Normally Required
Freeways, Showing Grade Separations and Interchanges
Railroads
Bridges
SEISMIC ELEMENT: FIGURE TWENTY
TWO MILES
CIRCULATION

2. Proposed transportation routes, facilities and structures should be evaluated for potential vulnerability and built only if problems can be sufficiently mitigated.

3. Highway bridges (overpasses), where seismic safety is questionable, should receive high priority for repair or replacement.

Hospitals

Recent legislation required geologic and engineering studies be conducted on new hospitals or additions to hospitals except type V buildings of 4000 square feet or less. Existing hospital structures have a wide variety of structure types and age of construction. Some hospitals may not be operational after a major earthquake. The following data was extracted from the NOAA report prepared for the Office of Emergency Preparedness (1972), A Study of Earthquake Losses in the San Francisco Bay Area: Santa Clara County has 11 general hospitals (100+ beds) with a total bed capacity of 3,798 and one mental health hospital (100+ beds) with 2,922 total bed capacity (1970 and 1971 data). A complete inventory of all health facilities shows 14 hospitals (3,951 beds), 56 nursing homes (4,446 beds), and several minor facilities.

> "Tactical and logistical problems to be faced by major hospitals and other health facilities during and after a severe earthquake will be considerable including many which will be unexpected. It is clear that the care of the injured immediately following the main shock would become one of the greatest area-wide problems. Although an attitude may be adopted in which it could be assumed that most of the hospitals would be in operation, the San Fernando earthquake of 1971 indicates that it is highly possible that many more hospital facilities and medical centers could be more severely damaged than originally suspected probable and thus be critically handicapped in useful post-earthquake recovery. Using the 1971 San Fernando earthquake as a model, it is not unrealistic to envision possibilities wherein a major hospital facility may become a burden rather than an aid after a major earthquake. In this regard all the hospitals in the 9 Bay Area counties therefore require close examination . . . .
>
> "Although a major medical facility may have the most modern equipment available, it may be located in an old structure, or although a new addition may have been completed in 1971, the main control center to the communication system could still be housed in the part of the building complex constructed before 1933 . . . ."

Santa Clara County has three hospitals whose date of construction, or age, of some of the original parts of the building complexes which are still being used in certain operations of the major hospitals built before 1933, four hospitals built between 1933 and 1960 and five hospitals built between 1960 and 1970.

> "There are two phases to meeting emergency health planning problems. First is the immediate post-disaster life saving phase. The concerns at this time are with the need of immediate medical attention in the care of the injured. The second phase is concerned with the basic

health problems and everyday needs of the survivors. This can be a protracted period of time wherein time and supplies are available to deal with the survivors. Both of these phases have been given consideration in the analysis of the major medical facilities made in this report . . . .

"Life hazard and property damage conclusions were derived from correlation of the isoseismal maps with the known earthquake resistance of each class of structural system . . . .

"It is significant to note that 40% of the major hospitals (in the Bay Area) still use portions of their building complexes which date back prior to 1933, the expected performance of which is therefore questionable. In regard to construction types, 5% of all the major hospitals located in the 9 San Francisco Bay Area counties are of brick construction of the type which performs poorly even during moderate earthquakes. According to Bureau of Planning and Construction (Sacramento), one of these in the City of San Francisco was constructed in two periods, 1916 and 1934, and is known to have brick masonry filler walls, with questionable mortar joints, designed to serve as lateral bracing against earthquake loading. This construction type performs poorly even in moderate shocks. Many of the parapets in this building are also reported to be in very poor condition."

Santa Clara County has eight hospitals of concrete construction type, one steel, one brick, and two of mixed construction type.

"With respect to multistory hospitals, several will have to be evacuated if heavily damaged, even though they are not subject to total collapse. Others will have to be evacuated pending inspection by qualified engineers to determine whether their structural integrity has been compromised beyond acceptable levels . . . ."

Santa Clara County has seven hospitals with one to four stories and five with five to eight stories.

"Local major hospitals resources will be diminished as a result of building damage, deaths, injuries, loss of medical supplies, loss of utility services, and damage to vertical circulation system . . . .

"Based on the bed occupancy rate, location and physical characteristics of the hospital building, the total number of deaths and injuries to occupants and personnel in the building were computed for the six earthquakes for three assumed times of day: 2:00 p.m., 4:30 p.m., and 2:30 a.m. . . . .

"Santa Clara County located between the two faults, would be subjected to major damage from major earthquake on either fault."

The upper credible limit for total loss and injuries within Santa Clara County hospitals for 2:00 p.m. or 4:30 p.m. is 463 deaths and 2,874 injuries and for 2:30 a.m. is 194 deaths and 1,208 injuries for an 8.3 Richter magnitude earthquake on the San Andreas Fault. For the same magnitude earthquake on the Hayward Fault, the projected deaths would be 507 and 212 respectively and 3,178 and 1,335 injuries for the same times of day.

"The losses of medical supplies stored in a hospital building is a function of two variables: (1) loss of supplies stored in fragile containers falling from their shelves and/or equipment falling off counter tops, and (2) building collapse on supplies and equipment rendering them useless . . . .

"By relating magnitudes and dollar loss to hospital supplies and equipment, the conceivable upper limit percentile dollar losses would be in the following ranges:

Magnitude 8.3	60 to 70% loss
Magnitude 7.0	20 to 30% loss
Magnitude 6.0	1 to 3% loss

The Medical Catastrophic Disaster Plan for Santa Clara County is designed to provide first aid care, handling and distribution of people to medical facilities. The County's Operational Area Emergency Plan has a Medical and Health Service section which should provide emergency medical and health services such as emergency medical care, vital statistics, coordination of mortuary operations, and coordination of medical and health operations for cities and towns within Santa Clara County. The County Director of Medical Institutions will have overall coordination of casualty care and treatment including the establishment of hospitals and field units. The County Health Administrator provides medical manpower, material, staff communications, transportation, information, and office services. Each city appoints a physician to serve as its Chief of Medical and Health Services which will carry out its own emergency plan as well as modifying its own operation to conform to State and Operational Area policies and coordinating instructions. Nursing, convalescent, and mental hygiene homes will provide minimum nursing care for less seriously ill or injured bed patients to lessen the burden on medical care facilities of greater capability. Emergency medical care services will be provided by existing and related facilities, such as hospitals, nursing and convalescent homes, non-hospital clinics, and clinical laboratories, and when conditions require, by emergency first aid stations and packaged disaster hospitals.

There are six packaged disaster hospitals in Santa Clara County. The units are stored at or near San Jose Hospital, O'Connor Hospital, El Camino Hospital, Good Samaritan Hospital, Valley Medical Center, and Wheeler Hospital. Each packaged disaster hospital consists of 200 folding cots, medical supplies, operating equipment, a large water tank and two generators. It does not contain any covering so the cots and equipment must be set up in a building such as a school or other structure. It takes 24-36 hours to set up all the equipment in a packaged hospital unit. It would take two large moving vans to transport each unit. Not many people have been trained to set up the units. There are thirty package Emergency First Aid Stations, each of which contains 74 litter cots, bandages, splints, blankets, etc. These units are distributed throughout the cities and the unincorporated area. Most of these units are about twenty years old and may be in a deteriorated condition. There are no funds currently available to replenish or replace deteriorated equipment in either the packaged disaster hospitals or emergency first aid stations.

The location of the packaged disaster hospitals within close proximity to the existing hospitals is significant when looking at the total County. Figure 3

shows the hospital locations, major roadways, bridges, and separated grade crossings. If certain freeway overpasses and bridges crossing creeks were to collapse, the population within certain areas would be restricted for a period of time to whatever medical facility or aid was available within an isolated area. On the valley floor, most sectors surrounded by freeways have a hospital available to them. In some cases, such as Milpitas and the Sunnyvale/Santa Clara area, the existing hospital may not have sufficient capacity to handle the population in that sector. Hillside residents such as Los Altos Hills and the area west of Lexington Reservoir might also be isolated, either by freeway overpass collapses or landslides across roads around Lexington Reservoir.

Public Buildings

The earthquake resistance of existing public buildings has not been surveyed by this study. Figure 21 shows most public and quasi-public buildings. Many city halls are designated as emergency operations centers and community shelters for emergencies. The community shelter surveys done in the past were based on protection from radiation fallout. A structural engineering and geologic site analysis is needed for structures which are supposed to be functional after an earthquake. This would include fire and police stations, civic centers, and other structures used as emergency operations centers, treatment of the injured and as large scale shelter for people whose housing is not habitable after a disaster.

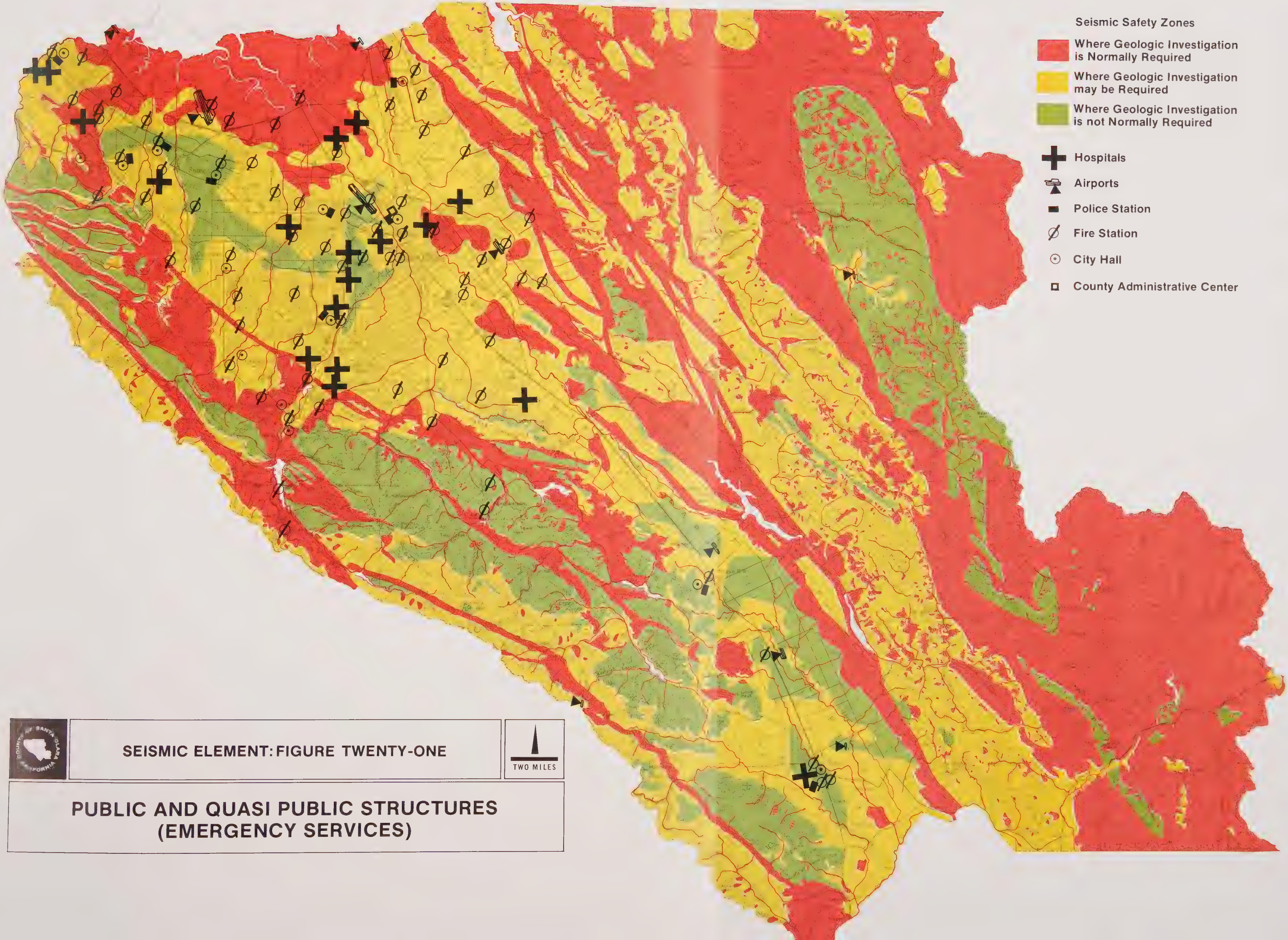
Schools

Public schools have been more thoroughly investigated with relationship to earthquake hazards than any other category of use structure. The Field Act, passed by the State Legislature in 1933 after the Long Beach earthquake, requires that all public schools be designed for the protection of life and property. Until a few years ago, a geologic and soils engineering report was not required of new school sites, so many well-constructed schools were placed on unsafe building sites, such as earthquake faults and active landslides. All of the public school buildings in Santa Clara County used as classrooms meet Field Act requirements.

URBAN DEVELOPMENT/OPEN SPACE

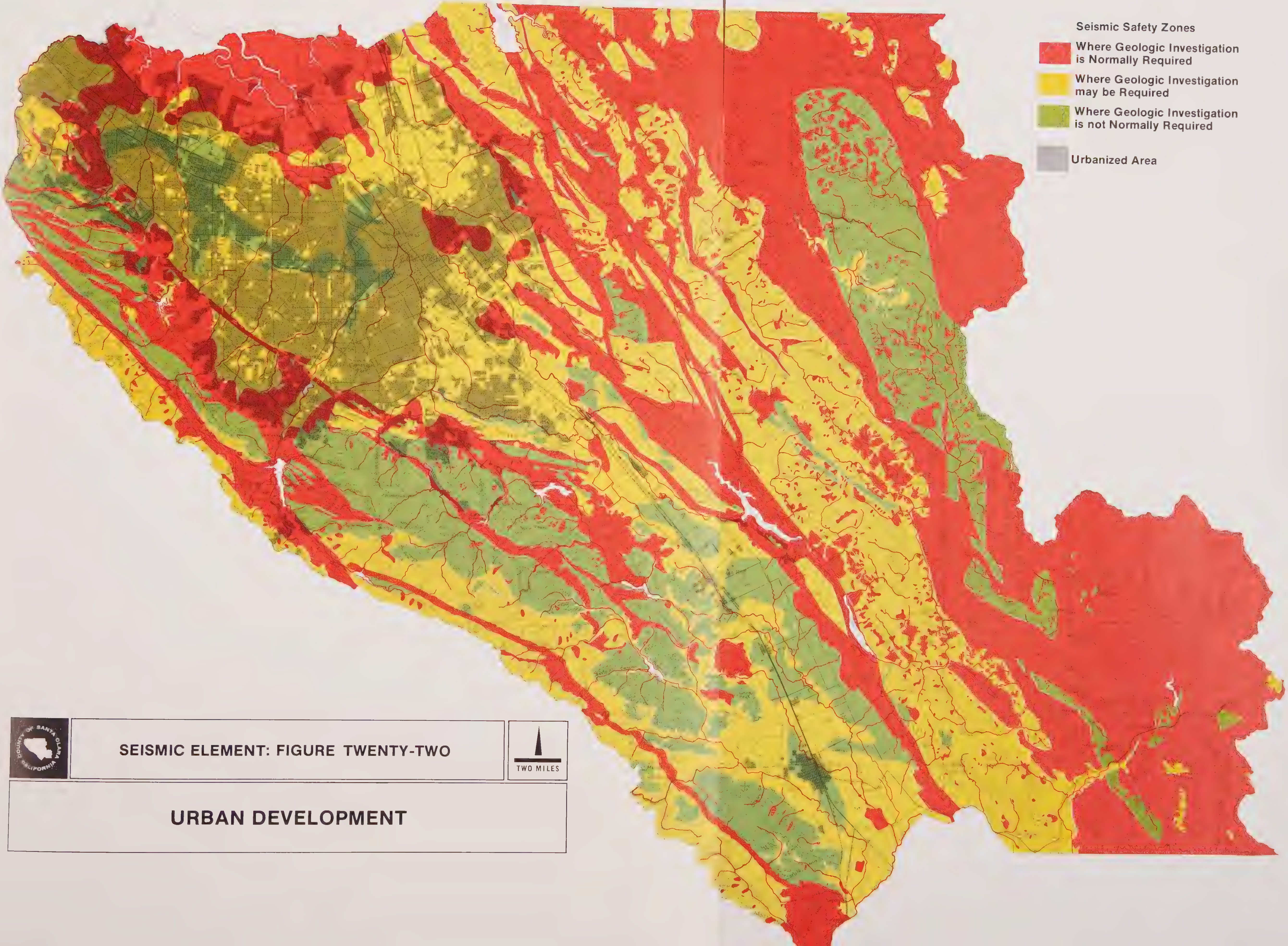
Local governments in recent years have made a serious effort to curb urban sprawl because of its cost to the public to provide urban services and more recently the difficulties of commuting with gasoline shortages and high costs. From a seismic safety perspective, the geologic hazards run the spectrum in both the present urbanized and undeveloped area (figure 22). A highly urban setting in tall structures with elevators that may not operate after an earthquake or parapets falling from older masonry buildings on people or cars in the street below would probably maximize loss of life when contrasted with very low density development on the outer fringes.

The recently adopted Urban Development/Open Space Plan categorizes all land in the County as either urban or nonurban using the cities' Urban Service Areas as the defining boundaries. That Plan, in essence, carries out a resolution adopted by the Board of Supervisors in 1967 which: "discourages applications for zone changes and use permits in those situations where the development of



SEISMIC ELEMENT: FIGURE TWENTY-ONE

PUBLIC AND QUASI PUBLIC STRUCTURES
(EMERGENCY SERVICES)



SEISMIC ELEMENT: FIGURE TWENTY-TWO

URBAN DEVELOPMENT

real property for residential, commercial, industrial, and all other urban uses requires the existence of various public utilities and facilities such as water and storm and sanitary sewers, and such facilities are not available within the unincorporated territory of the County." The cities now submit each year their Urban Service Areas which delineate on a map those areas to which each city will provide urban services within the next five years.

If the presently urbanized area is compared with the Seismic Element Zone, there are obvious "mismatches." As noted earlier in the report, most planning and development proceeded with little knowledge of geologic hazards until recent years.

There are a number of measures which can be used to reduce the seismic risk in both the urbanized and undeveloped area. <u>In the unurbanized area</u>, especially where there are other factors that favor open space usage such as critical environmental conditions and lack of access, <u>avoidance of hazards</u> can be emphasized by changes in land uses proposed and permitted in the general plan and existing zoning. This may mean planning and acquiring permanent open space such as parks and lower flood plains or lessening the density of land usage from suburban level to ranchette or agricultural zoning. Avoidance procedures should also be reinforced by not extending urban services and facilities to those areas and mitigation measures such as geologic site investigations.

Given the heavy capital investment already committed to the presently urbanized area, we cannot abandon those locations at this time. A policy of mitigation should be instituted to lessen the potential seismic hazards. Future urban development should be required to have geologic site investigation where indicated in the seismic zones and critical structures should be designed using the "Recommended Lateral Force Requirements" prepared by the Structural Engineers Association of California. Without special seismic design, it may be more appropriate to limit structural types in certain areas such as high-rise structures on deep soil deposits. The level of design and investigation should also relate to the nature of occupancy (voluntary/involuntary and high density/low density). Detailed geologic mapping at a scale of 1" = 200' or 400' is needed for urban areas. For existing structures, a long range inspection program should be formulated with better code enforcement based on the critical use of the structures and nature of occupancy.

A post-earthquake land use contingency plan should be developed by each jurisdiction. Ideally, this would mean visualizing an area solely from a geologic hazard and environmental factors perspective. Given sufficient funds to buy out development rights or arrange land swaps for property owners to relocate in a comparable area with a lower level of seismic risk, where would planners and decisionmakers choose the new urban center--perhaps on the edges of the valley or bands across the valley? Much of the fixed network of utilities would probably be damaged after a major quake, so relocation at that time would not be that much more expensive. While it is a normal human preference not to think about such a catastrophic happening, a post-earthquake land use contingency plan could avoid duplicating past mistakes and open opportunities for redevelopment in areas not considered because of the constraints imposed by existing urban patterns.

URBAN DEVELOPMENT/OPEN SPACE RECOMMENDATIONS:

1. Where urban development has already occurred and there has been a heavy capital improvement with urban services available, mitigation procedures should be used for urban development:

   a. A geologic investigation should be conducted on a scale commensurate with development where geologic data indicates there is a known or suspected problem.
   b. Site preparation should be directed at long term geologic stability as well as other environmental enhancement.
   c. Critical structures should be designed and constructed above and beyond Uniform Building Code where such measures are deemed necessary from available geologic and engineering data. Critical structures are those structures (1) needed after a disaster: emergency communications, fire stations, hospitals, bridges, and overpasses; (2) whose continued functioning is critical: major power lines and stations, water lines, and other utilities; and (3) whose failure might be catastrophic: large dams.
   d. Each jurisdiction should develop a long range inspection program for hazardous structures. Priorities for the inspection program should be based on critical nature of structure after a disaster and levels of occupancy (high vs. low and involuntary vs. voluntary).

2. Where urban development has not yet occurred such as the hillside and parts of the baylands that have geologic constraints associated with environmental factors such as steep slopes, flooding, fragile or scarce wildlife and vegetation, and little or no urban services and facilities, the major land uses should be largely open space uses.

3. Urbanization of hazardous areas should be discouraged by public agencies such as the Local Agency Formation Commission (which deals with annexations and formation of special districts) and planning commissions (for general planning and zone changes).

GLOSSARY OF SELECTED GEOLOGIC TERMS

active fault For the purposes of this report, an active fault is a fault along which ground displacement at or near the surface (within a few tens of feet) during the last 11,000 years (Holocene age) can be demonstrated.

alluvium A general term for loose unconsolidated deposits of rock, mineral, and soil material accumulated in streams, rivers, lakes, and fans at the foot of mountain slopes, all through the mechanism of running water.

anticline A fold in rock strata that is convex upward, resembling an arch.

aquifer A body of rock that contains sufficient saturated permeable material to conduct ground water and to yield economically significant quanitites of ground water to wells and springs.

bedding A collective term referring to the originally horizontal arrangement of beds or layers in a sequence of sediments or sedimentary rocks.

chert A hard, dense sedimentary rock composed chiefly of the mineral quartz--often closely associated with limestone.

clay A collective term referring to a series of fine-grained minerals, formed in large part from the weathering of rocks, and which may exhibit plastic properties under varying moisture conditions. Clay minerals are common in most soils and are the chief constituents of shale and mudstone.

cobble A rounded rock fragment of particular size (between 64 and 256 millimeters in diameter), intermediate in size between a pebble and a boulder.

colluvium A general term for loose, often nonuniform, unconsolidated deposits on a slope, accumulated through the mechanism of gravity.

conglomerate A sedimentary rock composed of rounded gravel- and sand-size rock fragments.

crust (of the Earth) The outermost layer or shell of the earth as seen in cross section. The crust ranges in thickness from 5 to 70 kilometers, being thinnest under the oceans and thickest under high mountain ranges.

debris flow (debris flood) A partly hydrologic phenomenon involving a rapid mass movement of a mixture of water, loose rock, and soil debris (colluvium and alluvium). Usually occurs when an abnormally large volume of runoff water picks up and transports large volumes of colluvium and alluvium and is thereby transformed into a dense, fluid, rapidly flowing mass. This mass is generally guided downhill by existing stream channels, commonly floods areas adjacent to those channels, and then deposits large volumes of the suspended debris wherever the slopes flatten and the flow velocity decreases.

deposition (sedimentation) A geological process resulting in the accumulation or placement of sedimentary material.

depositional contact A contact between two rock units formed by the deposition of sedimentary material on top of another rock through the mechanism of water, wind, or glacial ice.

differential settlement (consolidation subsidence) Uneven subsidence of the ground surface during earthquakes--due either to liquefaction or consolidation of underlying materials.

diurnal Having a distinctive daily behavior.

dyne A unit of force in the metric system equal to the force that would give a free mass of 1 gram an acceleration of 1 centimeter per second per second.

earth flow A type of landslide involving a downslope movement of water-saturated, weathered rock over a discrete surface as a well-defined tongue-like mass. Some earth flows are induced by liquefaction during earthquake shaking (in which case they are commonly called flow slides).

earthquake A sudden shaking of the earth caused principally by the abrupt release of slowly accumulated strain through the action of sudden displacement of bedrock. Commonly, geologists refer to a closely related series of earthquakes as one earthquake; e.g., San Francisco 1906 earthquake refers to many related events of different magnitudes. See Appendix F, table F-1, for definition of minor, moderate, major, and great earthquakes.

en echelon A pattern of folds or faults characterized by staggered, step-like arrangement, in which individual parallel features are offset from and overlapped with each other in one consistent direction--as shingles on a roof viewed in cross section.

epicenter (of an earthquake) That point on the earth's surface which is vertically above the subsurface point of initial energy release during an earthquake.

erg A unit of work in the metric system equal to the force of 1 dyne acting through a distance of 1 centimeter.

erosion Geologic processes that result in the loosening and transportation of earthy or rock material from high points to low points on the earth's surface.

fault A fracture in the earth's crust forming a boundary between rock masses that have moved relative to each other.

fault creep (tectonic creep) Slow, spasmodic displacement of rock masses along a fault not accompanied by earthquakes. Displacement commonly totals less than 3 centimeters per year.

fault gouge Soft, clay-rich pulverized material along faults containing fragments of sheared rock commonly derived from bedrock adjacent to the fault.

fault plane The geometric plane representing a fault, defined by the fracture between moving rock masses in the earth's crust.

fault system A group of faults or fault zones related to a distinct period of tectonic deformation.

fault trace The intersection of the fault plane with the ground surface.

fault zone A series of generally subparallel, locally branching faults, spaced closely together and forming a complex pattern of fault traces on the ground surface. Rocks between these traces may be severely deformed and may contain rock units unlike the bedrock on either side of the fault zone.

focal depth The vertical distance from the epicenter to the earthquake focus (hypocenter).

focus (of earthquake) see **hypocenter.**

fold A bend in formerly horizontal rock strata--anticline, syncline, monocline.

fossil The prehistoric remains or traces of animals or plants naturally preserved in the earth's crust (usually in sedimentary rocks).

geodesy A science concerned with the determination of the size and shape of the earth and the precise location of points on its surface.

Geodimeter An electronic-optical instrument designed to measure long distances (greater than several kilometers) with great precision.

geologic structure That part of the geology of a region that pertains to the attitude of the rocks, the kind and amount of the deformation, if any, which they have undergone, and the distribution and interrelationships of all these features.

geology The study of the planet earth, its material, history, record of life, land features, and processes acting upon it.

geophysics The study of the physics of the earth, concerning properties of the solid earth, atmosphere, hydrosphere, and magnetosphere.

hydrology The science that deals with continental water: its properties, distribution, and circulation on the land surface, in the underlying soil and rocks, and in the atmosphere.

hypocenter (of an earthquake) The point beneath the earth's surface representing the initial energy release during an earthquake and the origin of the first earthquake shock waves.

igneous rocks Rocks formed by the cooling of melted or partially melted rock material.

isopach A line of equal thickness of a geologic unit.

intensity, Mercalli A rating on the Mercalli intensity scale (modified) based on observed damage and personal reaction, describing the earthquake effects at a given location. Ratings of I to XII are assigned according to the Modified Mercalli intesity scale of 1931 (see Appendix F).

intrusive rocks A class of igneous rocks--those formed by the cooling of molten material beneath the earth's surface.

landslide A general term for the downslope movement of a mass of soil, surficial deposits, or bedrock. Landslide movement is relatively rapid compared with soil creep movement. Also used more generally by some geologists to indicate the area of sliding or even the deposits resulting from landslide movement.

lateral fault A type of fault characterized by horizontal displacement or rock masses. Right lateral fault displacement involves movement such that to an observer on one block (one side of the fault) the block across the fault appears to have moved to the right.

lateral spreading A type of ground failure on gently sloping ground involving the lateral movement of a generally tongue-shaped mass of material toward an exposed steep face (usually the steep banks of a stream channel). Lateral spreading may be induced by liquefaction of near-horizontal alluvial layers exposed in the steep face.

limestone A sedimentary rock composed chiefly of the mineral calcite, derived from the accumulation of skeletal remains of organisms and/or the chemical precipitation of calcite (calcium carbonate).

liquefaction A process by which water-saturated, granular material is transformed from a solid state to a liquid state (quicksand). Such transformation occurs in loose, water-saturated, clay-free sands or silts during earthquake vibrations. Such vibrations result in compaction, increased pore water pressure, and finally expulsion of water from the material.

lithologic Pertaining to or descriptive of a rock type.

low velocity rocks Herein: Rocks in which the shear wave velocity is less than that normally expected because of tectonic shearing.

lurch cracks (lurching) Cracks (commonly in soft, water-saturated material) which open as the result of strong ground shaking during an earthquake.

magnitude, Richter A measure of the radiated energy of an earthquake as determined by seismograph data.

Mercalli intensity, Modified See **intensity.**

metamorphic rocks Rocks derived from pre-existing rocks of various types, formed as the result of chemical or physical alteration under severe conditions of heat, pressure, and fluid saturation--usually below the earth's surface.

mudstone A sedimentary rock composed chiefly of mud and silt and which is massive and breaks into generally equidimensional blocks.

normal fault A type of fault characterized by vertical displacement on an inclined fault plane and downward relative displacement of the rock mass above the fault plane.

pebble A rounded rock fragment of particular size (between 2 and 64 millimeters in diameter).

plates Large continent-sized blocks of rock having a large width-to-thickness ratio, part of a mosaic comprising the crust of the earth.

potentially active fault For the purposes of this report, a potentially active fault is a fault along which ground displacement during the last 3 million years (Quaternary age) can be demonstrated or along which fault such displacement is suspected.

reverse fault A type of fault characterized by an angle of inclination (from the horizontal) greater than 45°, and a relative displacement of the upper rock mass up and over the lower rock mass. (See **thrust fault).**

Richter magnitude See **magnitude.**

rockfall A type of landslide involving a relatively free fall of newly detached fragments of bedrock of any size from a cliff or other steep slope.

sand boil An eruption of sandy water from ground cracks resulting in mound-shaped deposits of sand intermittently along these cracks. Sand boils often occur subsequent to liquefaction of underlying sandy materials.

sandstone A sedimentary rock composed of rock and mineral fragments of sand size ($1/2$ millimeter to $1/16$ millimeter).

sedimentary rocks Rocks formed by the hardening of sediments that have accumulated through the mechanism of running water, wind, or glacial ice.

sediment An accumulation of loose mineral and rock fragments formed through the mechanism of running water, wind, or glacial ice.

seiche A standing wave in the surface of an enclosed body of water that may be set in motion by earthquake shaking, winds, or tidal currents. Wave periods commonly range from a few minutes to several hours.

seismograph An instrument to record vibrations of the earth, especially earthquakes.

seismology The study of earthquakes, their origins, and related phenomena.

shale A sedimentary rock composed of compressed mud and silt which can be easily split parallel to the bedding, causing the rock to break into thin chips.

shear zone A tabular zone of fractured and sheared rock material (usually containing much clay) which is derived from the disruption and alteration of bedrock during displacement along a fault. In Franciscan rocks, shear zones are much wider and more extensive than in younger rock units--reflecting a different style of deformation.

shrink-swell potential A soil limitation rating defined by the U.S. Department of Agriculture - Soil Conservation Service to describe the relative amount of volume change in a soil due to clay which swells when wetted and shrinks when dried.

sill An intrusive igneous rock in a tabular form, parallel to the bedding or layering of the intruded rocks.

soil Those earth materials derived from surficial and bedrock geologic units and so weathered and modified by physical, chemical, and biologic agents that they will support rooted plants.

soil creep The gradual and steady downslope movement of soil and loose rock material. Usually occurs on steep slopes.

source mechanism A collective term describing the origin of seismic energy and mode of energy release, including such factors as size of the displacement surface along the fault, time history of the displacement, direction of the first motion of a seismic shaking, and amount of rock strain reduction associated with the earthquake.

stratum (plural strata) A layer in an interbedded series of sediments or sedimentary rocks.

strong motion instrument An instrument designed to record and measure relatively large earthquake ground motions near the earthquake epicenter. The design is basically that of a seismograph, altered to withstand and record large vibrations.

surface fault rupture Rupture of the ground surface along a fault trace due to displacement of rock masses on either side of the fault.

surficial deposits Unconsolidated deposits which are formed at the earth's surface (commonly by the action of gravity, running water, or moving glacial ice) and which overlie bedrock geologic units.

syncline A fold in rock strata that is convex downward, resembling a trough.

talus Fragmented rock material which has collected at the base of a steep slope.

tectonic blocks Large angular to rounded, commonly elliptically shaped masses of relatively hard rocks surrounded by a clay-rich sheared matrix. Occurs within shear zones and fault gouge. In the shear zones of the Franciscan rocks, these blocks range from "fist size" to masses more than 1 mile long.

tectonic creep See **fault creep.**

thrust fault A type of fault characterized by an angle of inclination (from the horizontal) less than 45° and a relative displacement of the upper rock mass up and over the lower rock mass. (See **reverse fault)**

topography The physical features or general configuration of a land surface, specifically relief and slope; can be depicted in map form by contour line patterns.

tsunami (seismic sea wave) A water wave generated by any large-scale, short-duration disturbance on the floor of the ocean, such as a submarine earthquake, submarine landslide, or volcanic eruption. Commonly misnamed "tidal wave".

unconformity A surface of erosion or nondeposition which separates overlying younger rocks from underlying older rocks and which represents a significant time gap between ages of the overlying and underlying rock units.

volcanic rocks A class of igneous rocks--those formed from the cooling of molten material poured out upon or intruded very near the earth's surface.

wave amplitude One-half the wave height.

REFERENCES

*Alden, W.C., 1928, Landslide and flood at Gros Ventre, Wyoming: American Institute of Mining and Metallurgical Engineers Transactions, v. 76, p. 347-361.

Allen, C.R., *et al.*, 1968, The Borrego Mountain earthquake, April 8, 1968: California Division of Mines and Geology Mineral Information Service, v. 21, no. 7, p. 103-106.

Allen, J.E., 1946, Geology of the San Juan Bautista quadrangle, California: California Division of Mines Bulletin 133, 112 p.

Anderson, D.L., 1973, The San Andreas fault, *in* Continents adrift: Scientific American, a collection of readings from Scientific American, p. 143-157.

Bailey, E.H., and Everhart, D.L., 1964, Geology and quicksilver deposits of the New Almaden District, Santa Clara County, California: U.S. Geological Survey Professional Paper 360, 206 p.

Barosh, P.J., 1969, Use of seismic intensity data to predict the effects of earthquakes and underground explosions in various geologic settings: U.S. Geological Survey Bulletin 1279, 93 p.

Barrows, A.G., Kahle, J.E., Weber, F.H. Jr., and Saul, R.B., 1971, Map of surface breaks resulting from the San Fernando, California, earthquake of February 9, 1971: California Division of Mines and Geology Preliminary Report 11.

Bartsch, S.R., Geology of the Oak Flat Ranch area, Santa Clara County, California (tentative title): San Jose State University, unpublished M.S. thesis, in preparation.

*Bates, H.W., 1875, The naturalist on the River Amazon: John Murray, London, p. 249-250.

Bauer, P.G., 1971, Geology of the Redwood Retreat-Croy Ridge area of Santa Clara County: Unpublished M.S. thesis, San Jose State University, 74 p.

Bennett, R.E., 1972, Geology of the Dexter Canyon area, Santa Clara County, California: Unpublished M.S. thesis, San Jose State University, 67 p.

Berggren, W.A., 1972, A Cenozoic time scale--some implications for regional geology and paleobiogeography: Lethia, v. 5, no. 2, p. 195-215.

Berkland, J.O., 1974, Geologic map vicinity of Pacheco Peak, Santa Clara County, California: Unpublished data.

Berkland, J.O., *et al.*, 1972, What is Franciscan?: American Association of Petroleum Geologists Bulletin, p. 56, no. 12, p. 2295-2302.

Bishop, C.C., Geologic map of parts of the Chittenden and San Juan Bautista quadrangles, Santa Clara, San Benito, Santa Cruz, and Monterey Counties, California: California Division of Mines and Geology, in progress.

*Blackwelder, Eliot, 1928, Mudflow as a geologic agent in semiarid mountains: Geological Society of America Bulletin, v. 39, p. 465-484.

*Indicates references pertaining to landslides.

*Blanc, R.P., and Cleveland, G.B., 1968, Natural slope stability as related to geology, San Clemente area, Orange and San Diego Counties, California: California Division of Mines and Geology Special Report 98, 19 p.

Bolt, B.A., 1970, Causes of earthquakes *in* Wiegel, R.L., editor, Earthquake engineering: Prentice-Hall, Englewood Cliffs, New Jersey, p. 21-45.

Bolt, B.A., 1972, Seismicity *in* Proceedings of the international conference on microzonation for safer construction-research and application, p. 13-28.

Bolt, B.A., Lomnitz, C., and McEvilly, T.V., 1968, Seismological evidence on the tectonics of central and northern California and the Mendocino escarpment: Bulletin of the Seismological Society of America, v. 58, no. 6, p. 1725-1767.

Bonilla, M.G., 1970, Surface faulting and related effects *in* Wiegel, R.L., editor, Earthquake engineering: Prentice-Hall, Englewood Cliffs, New Jersey, p. 47-74.

Bonilla, M.G., and Gates, G.O., 1961, Possible earthquake hazards at the site of proposed Foster City, San Mateo County, California: U.S. Geological Survey Report to the Committee on Government Operations, House of Representatives, Appendix 1.

Borcherdt, R.D., 1970, Effects of local geology on ground motion near San Francisco Bay: Bulletin of the Seismological Society of America, v. 60, no. 1, p. 29-61.

Brabb, E.E., 1964, Subdivision of the San Lorenzo Formation (Eocene-Oligocene) west central California: American Association of Petroleum Geologists Bulletin, v. 48, no. 5, p. 670-679.

*Brigham, A.P., 1906, A Norwegian landslip: Geographical Society of Philadelphia Bulletin, v. 4, p. 292-296.

Brown, R.D., *et al.*, 1967, The Parkfield-Cholame earthquakes of June-August, 1966—surface geologic effects, water resources aspects, and preliminary seismic data: U.S. Geological Survey Professional Paper 579, 66 p.

Brown, R.D., Jr., and Lee, W.H.K., 1971, Active faults and preliminary earthquake epicenters (1969-1970) in the southern part of the San Francisco Bay region: U.S. Geological Survey Miscellaneous Field Studies Map, MF-307. Also as Basic Data Contribution No. 30, San Francisco Bay region environment and resources study: U.S. Geological Survey—U.S. Department of Housing and Urban Development.

Brown, R.D., Jr., and Wallace, R.E., 1968, Current and historic movement along the San Andreas fault between Paicines and Camp Dix, California, *in* Proceedings of conference on geologic problems of the San Andreas fault system: Stanford University Publications, Geological Sciences, v. XI, p. 22-41.

Bufe, C.G., and Tocher, Don, 1974, Central San Andreas fault; strain episodes, fault creep, and earthquakes: Geology, v. 2, no. 4, p. 205-207.

Burford, R.O., Allen, S.S., Lawson, R.J., and Goodreau, D.D., 1973, Accelerated fault creep along the central San Andreas fault after moderate earthquakes during 1971-1973 *in* Proceedings of the conference on tectonic problems of the San Andreas fault system: Stanford University Publications, Geological Sciences, v. XIII, p. 268-285.

*Buss, Ernst, and Heim, Albert, 1881, Der Bergstruz von Elm: J. Wuster und Cie, Geographischer Verlag, p. 163.

California Department of Water Resources, 1967, Evaluation of ground water resources, South Bay: California Department of Water Resources Bulletin 117, Appendix—Geology, plate 3.

California Department of Water Resources, 1968, Geodimeter fault movement investigations in California: Bulletin 116-6, 183 p.

California Department of Water Resources, in press, Evaluation of ground water resources, south bay (Santa Clara County study area): California Department of Water Resources Bulletin 118-1.1., v. 2.

Carter, C.H., 1970, Geology of the Pallassou Ridge area, California: San Jose State University unpublished M.S. thesis, 70 p.

Christensen, M.N., 1966, Quaternary of the California Coast Ranges *in* Bailey E.H., editor, Geology of northern California: California Division of Mines and Geology Bulletin 190, p. 305-314.

Cluff, L.S., and McClure, F.E., 1970, Geology and structural engineering - a report submitted to the Baylands Subcommittee of the Planning Policy Committee of Santa Clara County - published in summary form *in* Santa Clara County Planning Department, 1972, A policy plan for the baylands of Santa Clara County.

Cluff, L.S., and Steinbrugge, K.V., 1966, Hayward fault slippage in the Irvington-Niles districts of Fremont, California: Bulletin of the Seismological Society of America, v. 56, no. 2, p. 257-279.

Cooper-Clark & Associates, 1974, Final technical report to the City of San Jose, San Jose Geotechnical Study.

Cotton, W.R., 1972, Preliminary geologic map of the Franciscan rocks in the central part of the Diablo Range, Santa Clara and Alameda Counties, California: U.S. Geological Survey, San Francisco bay region environment and resources planning study, Basic Data Contribution 39.

*Crandell, D.R., and Fahnestock, R.K., 1965, Rockfalls and avalanches from Little Tahoma Peak on Mount Rainier, Washington: U.S. Geological Survey Bulletin 1221-A, 30 p.

Crittenden, M.D. Jr., 1951, Geology of the San Jose-Mount Hamilton area, California: California Division of Mines Bulletin 157, 74 p.

Cummings, J.C., 1968, The Santa Clara formation and possible post-Pliocene slip on the San Andreas fault in central California *in* Proceedings of the conference on geologic problems of the San Andreas fault system: Stanford University Publications, Geological Sciences, v. XI, p. 191-207.

Dibblee, T.W. Jr., 1966, Geology of the Palo Alto quadrangle, Santa Clara and San Mateo Counties, California: California Division of Mines and Geology Map Sheet 8.

Dibblee, T.W. Jr., 1972a, Preliminary geologic map of the San Jose East quadrangle, Santa Clara County, California: U.S. Geological Survey open file report.

Dibblee, T.W. Jr., 1972b, Preliminary geologic map of the Milpitas quadrangle, Alameda and Santa Clara Counties, California: U.S. Geological Survey open file report.

Dibblee, T.W. Jr., 1972c, Preliminary geologic map of the Lick Observatory quadrangle, Santa Clara County, California: U.S. Geological Survey open file report.

*Indicates references pertaining to landslides.

Dibblee, T.W. Jr., 1973a, Preliminary geologic maps of the Gilroy Hot Springs quadrangle, the Gilroy quadrangle, the Mt. Sizer quadrangle, the Morgan Hill quadrangle, Santa Clara County, California, and the Mt. Madonna quadrangle, Santa Clara and Santa Cruz Counties, California: U.S. Geological Survey open file report.

Dibblee, T.W. Jr., 1973b, Preliminary geologic map of the Calaveras Reservoir quadrangle, Alameda and Santa Clara Counties, California: U.S. Geological Survey open file report.

Dickinson, W.R., *et al.*, 1972, Test of the new global tectonics; discussion: American Association of Petroleum Geologists Bulletin, v. 56, no. 2, p. 375-384.

Eckel, E.B., 1970, The Alaska earthquake, March 27, 1964; Lessons and conclusions: U.S. Geological Survey Professional Paper 546, 57 p.

Frames, D.W., 1955, Stratigraphy and structure of the lower Coyote Creek area, Santa Clara County, California: University of California, Berkeley, unpublished M.A. thesis.

Fugro, Inc., 1973, Geologic investigation, Silver Creek Hills, San Jose, California: Unpublished data.

*Fuller, M.L., 1912, The New Madrid earthquake: U.S. Geological Survey Bulletin 494, 119 p.

Geological Society of London, 1964, The Phanerozoic time-scale: a symposium: Geological Society of London Quarterly Journal, v. 120, supplement, p. 260-262.

Goldman, H.B., 1973, Hayward shoreline environmental analysis: Hayward Area Shoreline Planning Agency, 36 p.

Greely, A.W., 1906, Special report of Major General Adolphus W. Greely, U.S.A., commanding the Pacific Division, on the relief operations conducted by the military authorities of the United States at San Francisco and other points.

Gutenberg, B., 1957, Effects of ground on earthquake motion: Bulletin of the Seismological Society of America, v. 47, no. 3, p. 221-250.

Gutenberg, B., and Richter, C.F., 1949, Seismicity of the Earth: Princeton University Press, Princeton, New Jersey.

*Hadley, J.B., 1964, Landslides and related phenomena accompanying the Hebgen Lake earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-K, p. 107-138.

Hadley, J.W., 1970, Letter to the editor: California Division of Mines and Geology Mineral Information Service, v. 23, no. 1, p. 16.

Hall, C.E., 1974, San Felipe area geologic map: U.S. Bureau of Reclamation unpublished data.

*Heezen, B.C., and Ewing, Maurice, 1952, Turbidity currents and submarine slumps, and the 1929 Grand Banks earthquake: Journal of Science, v. 250, p. 849-873.

*Heim, Albert, 1882, Der Bergsturz von Elm: Deutsche geol. Gell., Zeitschr., v. 34, p. 74-113, 435-439.

*Heim, A., Moser, R., and Burkli-Ziegler, A., 1888, Die Catastrophe von Zug 5 Juli 1887: Zurich, Hofer und Burger, 49 p.

Helley, E.J., and Brabb, E.E., 1971, Geologic map of Late Cenozoic deposits, Santa Clara County, California: U.S. Geological Survey, San Francisco bay region environment and resources planning study, Basic Data Contribution 27.

*Herling, E.W., and Stafford, Gifford, 1952, Orinda slide: California Highways and Public Works, v. 31, nos. 1 and 2, p. 45.

Hill, M.R., 1969, Replies to letters to the editor: California Division of Mines and Geology Mineral Information Service, v. 22, no. 5, p. 76-77.

Housner, G.W., 1970, Strong ground motion *in* Wiegel, R.L., editor, Earthquake engineering: Prentice-Hall, Englewood Cliffs, New Jersey, p. 75-91.

Hudson, D.E., 1972, Strong motion seismology *in* Proceedings of the international conference on microzonation for safer construction-research and application, p. 29-60.

*Jahns, R.H., and Vonder Linden, K., 1973, Space-time relationships of landsliding on the southerly side of the Palo Verdes Hills, California, *in* Geology, seismicity, and environmental impact: Association of Engineering Geologists, Special Publication, October 1973, p. 123-138.

Klein, I.E., 1962, San Felipe division Engineering Geology Appendix: U.S. Bureau of Reclamation unpublished data.

*Krauskopf, K.B., Feitler, S., and Griggs, A.B., 1939, Structural features of a landslide near Gilroy, California: Journal of Geology, v. 67, p. 630-648.

Lawson, A.C., chairman, 1908, State Earthquake Investigation Commission, The California earthquake of April 18, 1906: Carnegie Institution of Washington, Publication 87 (reprinted in 1969 in two volumes-text and atlas of maps).

*Legget, R.F., 1962, Geology and engineering: McGraw-Hill, New York, 884 p.

Leighton, F.B., 1966, Landslides and hillside development *in* Lung R., and Proctor, R., editors, Engineering geology of southern California: Association of Engineering Geologists, Los Angeles Section, Special Publication, p. 149-200.

MacMudro, J., 1824, Papers relating to the earthquake which occurred in India in 1819: Philosophy Magazine, v. 63, p. 105-177.

Mayer-Rosa, D., 1973, Travel time anomalies and distribution of earthquakes along the Calaveras fault zone, California: Bulletin of the Seismological Society of America, v. 63, no. 2, p. 713-729.

McClure, F.E., 1974, Seismic structural engineering analysis for Santa Clara County Planning Department, California.

McCulloch, D.S., 1966, Slide-induced waves, seiching, and ground fracturing caused by the earthquake of March 27, 1964, at Kenai Lake, Alaska: U.S. Geological Survey Professional Paper 548-A, 41 p.

*McGill, J.T., 1959, Preliminary map of the landslides in the Pacific Palisades area, City of Los Angeles, California: U.S. Geological Survey Miscellaneous Geological Investigations Map I-284.

McKee, B.E., 1965, Geology of the Pacheco Pass-Gilroy Hot Springs area, California: California Division of Mines and Geology open file report.

*Indicates references pertaining to landslides.

McLaughlin, R.J., 1971a, Geologic map of the Sargent fault zone in the vicinity of Mt. Madonna, Santa Clara County, California: U.S. Geological Survey, San Francisco bay region environment and resources planning study, Basic Data Contribution 13.

McLaughlin, R.J., *et al.*, 1971b, Preliminary geologic map of the Loma Prieta-Mount Madonna area, Santa Clara and Santa Cruz Counties, California: U.S. Geological Survey open file map.

McLaughlin, R.J., and Sorg, D.H., 1974, Relationship of the Sargent-Berrocal fault zone to deformation of the Santa Clara Formation between Los Gatos and Los Altos Hills, California: Geological Society of America Abstracts with Programs, v. 6, no. 3, p. 217.

*Merriam, Richard, 1960, Portuguese Bend landslide, Palos Verdes Hills, California: Journal of Geology, v. 68, p. 140-153.

*Miller, W.J., 1931, The landslide at Point Fermin, California: Scientific Monthly, v. 32, p. 464-469.

*Moore, J.G., 1964, Giant submarine landslides on the Hawaiian Ridge: U.S. Geological Survey Professional Paper 501-D, p. D95-98.

Morton, D.M., and Streitz, R., 1967, Landslides: California Division of Mines and Geology Mineral Information Service, v. 20, no. 10, p. 123-129, and no. 11, p. 135-140.

Nason, R.D., 1973, Fault creep and earthquakes on the San Andreas fault *in* Proceedings of conference on tectonic problems of the San Andreas fault system: Stanford University Publications, Geological Sciences, v. XIII, p. 275-285.

Newman, W.L., 1970, Geologic time, the age of the earth: U.S. Geological Survey, pamphlet, 20 p.

Ortalda, R.A., 1948, Geology of the northern part of the Morgan Hill quadrangle, California: University of California, Berkeley, unpublished M.A. thesis.

Osbun, E.D., Geology of the Sveadal area, southern Santa Cruz Mountains, California (tentative title): San Jose State University, unpublished M.S. thesis, in preparation.

Osuch, L.T., 1970, Geology of the Three Sisters quadrangle, California: University of California, Berkeley, unpublished M.A. thesis, 59 p.

Pampeyan, E.H., 1970, Geologic map of the Palo Alto 7.5-minute quadrangle, San Mateo and Santa Clara Counties, California: U.S. Geological Survey, San Francisco bay region environment and resources planning study, Basic Data Contribution 2.

*Peebles, J.J., 1962, Engineering geology of the Cartwright Canyon quadrangle (Idaho): Idaho Bureau of Mines and Geology Pamphlet 127, 68 p.

Radbruch, D.H., Bonilla, M.G., *et al.*, 1966, Tectonic creep in the Hayward fault zone, California: U.S. Geological Survey Circular 525, 13 p.

Radbruch, D.H., 1968, Map showing recently active breaks along the Hayward fault zone and the southern part of the Calaveras fault zone, California: U.S. Geological Survey, open file map.

Richter, C.F., 1958, Elementary seismology: W.H. Freeman and Co., San Francisco, 768 p.

Rogers, A.M., *et al.*, 1974, Topographic effects on ground motion for incident P waves; a model study: Bulletin of the Seismological Society of America, v. 64, no. 2, p. 437-456.

Rogers, T.H., 1972, Environmental geologic analysis of the Santa Cruz Mountains study area, Santa Clara County, California: California Division of Mines and Geology Open File Report 72-21.

Rogers, T.H., Geologic map of the San Felipe quadrangle: California Division of Mines and Geology, in progress.

Rogers, T.H., and Armstrong, C.F., 1973, Environmental geologic analysis of the Monte Bello Ridge mountain study area, Santa Clara County, California: California Division of Mines and Geology Preliminary Report 17, 50 p.

Rogers, T.H., and Nason, R.D., 1971, Active displacement on the Calaveras fault zone at Hollister, California: Bulletin of the Seismological Society of America, v. 61, no. 2, p. 399-416.

Santa Clara County Planning Department, 1972, A policy plan for the baylands of Santa Clara County: County of Santa Clara, 84 p.

Savage, J.C., *et al.*, 1973, Geodimeter measurements along the San Andreas fault *in* Proceedings of the conference on tectonic problems of the San Andreas fault system: Stanford University Publications, Geological Sciences, v. XIII, p. 44-53.

Seed, H.B., 1970, Soil problems and soil behavior *in* Wiegel, R.L., editor, Earthquake engineering: Prentice-Hall, Englewood Cliffs, New Jersey, p. 227-251.

Seed, H.B., 1974, Seismic ground shaking and liquefaction analysis for Santa Clara County Planning Department, California.

Seed, H.B. and Schnabel, P.B., 1972, Soil and geologic effects on site response during earthquakes *in* Proceedings of the international conference on microzonation for safer construction-research and application, p. 61-86.

Seed, H.B., and Wilson, S.D., 1967, The Turnagain Heights landslide, Anchorage, Alaska: American Society of Civil Engineers, Proceedings, v. 93, paper 5320, Journal Soil Mechanics and Foundation Division, no. SM4, p. 325-353.

*Selli, R., Trevisan, L., Carboni, G.C., Mazzanti, R., and Ciabatti, 1964, La frana del Vaiont: Annale del Museo Geologico de Bologna, serie 2, v. 32, 154 p.

*Sharp, R.P., and Nobles, L.H., 1953, Mudflow of 1941 at Wrightwood, southern California: Geological Society of America Bulletin, v. 64, p. 547-560.

*Sharpe, C.F.S., 1938, Landslides and related phenomena: Columbia University Press, New York, 137 p.

*Shreve, R.L., 1968, The Blackhawk landslide: Geological Society of America Special Paper 108, 47 p.

Simoni, T.R. Jr., Geology of the Loma Prieta area, Santa Clara and Santa Cruz Counties, California: San Jose State University, unpublished M.S. thesis, in preparation.

Slosson, J.E., 1969, The role of engineering geology in urban planning: Colorado Geological Survey Special Publication 1, p. 8-15.

*Indicates references pertaining to landslides.

Steinbrugge, K.V., 1970, Earthquake damage and structural performance in the United States, *in* Wiegel, R.L., editor, Earthquake engineering: Prentice-Hall, Englewood Cliffs, New Jersey, p. 167-226.

*Strahler, A.N., 1940, Landslides of the Vermillion and Echo Cliffs, northern Arizona: Journal of Geomorphology, v. 3, p. 285-301.

Thurlos, C., 1973, Tides and tidal datums, summary at the San Francisco Presidio: Unpublished report prepared for the State Lands Commission.

Tocher, D., 1960, Creep on the San Andreas fault, creep rate and related measurements at Vineyard, California: Bulletin of the Seismological Society of America, v. 50, p. 396-404.

Tocher, D., 1970, Letter to the editor: California Division of Mines and Geology Mineral Information Service, v. 23, no. 1, p. 17.

Trifunac, M.D., and Hudson, D.E., 1971, Analysis of the Pacoima Dam accelerograms, San Fernando, California, earthquake of 1971: Bulletin of the Seismological Society of America, v. 61, no. 5, p. 1393-1411.

*Troxell, H.C., and Peterson, J.Q., 1937, Flood in La Canada Valley, California, January 1, 1934: U.S. Geological Survey Water-Supply Paper 796-C, p. 53-98.

Tudor Engineering, 1973, Report to the Santa Clara County Flood Control and Water District on the bay lands salt water flood control planning study: Tudor Engineering, San Francisco, 157 p.

Udwadia, F.E., and Trifunac, M.D., 1973, Comparison of earthquakes and microtremor ground motions in El Centro, California: Bulletin of the Seismological Society of America, v. 63, no. 4, p. 1227-1254.

U.S. Department of Commerce, 1966, Earthquake history of the United States, part II - stronger earthquakes of California and western Nevada, 48 p.

Varnes, D.J., 1958, Landslide types and processes *in* Eckel, E.B., editor, Landslides and engineering practice: National Research Council, Highway Research Board, Special Report 29, p. 20-47.

Vorhis, R.C., 1967, Hydrologic effects of the earthquake of March 27, 1964, outside Alaska: U.S. Geological Survey Professional Paper 544-C, 54 p.

Wahler, W.A., & Associates, 1970, Scherrer Ranch ground water study, Santa Clara County, California: Unpublished data.

Wallace, R.E., 1970, Earthquakes recurrence intervals on the San Andreas fault: Geological Society of America Bulletin, v. 81, no. 10, p. 2875-2890.

Waller, R.M., 1966, Effects of the earthquake of March 27, 1964, on the hydrology of south-central Alaska: U.S. Geological Survey Professional Paper 544-A, p. A1-A28.

Wesson, R.L., Burford, R.D., and Ellsworth, W.L., 1973, Relationship between seismicity, fault creep, and crustal loading along the central San Andreas fault *in* Proceedings of the conference on tectonic problems of the San Andreas fault system: Stanford University Publications, Geological Sciences, v. XIII, p. 303-321.

Williams, J.W., *et al.*, 1973, Environmental geological analysis of the south county study area, Santa Clara County, California: California Division of Mines and Geology Preliminary Report 18, 41 p.

Willis, D.E., *et al.*, 1972, Seismological aspects of the Cannikin nuclear explosion: Bulletin of the Seismological Society of America, v. 62, no. 6, p. 1377-1395.

*Woodford, A.O., and Harriss, T.F., 1928, Geology of Blackhawk Canyon, San Bernardino Mountains, California: University of California Publication, Department of Geological Sciences Bulletin, v. 17, p. 265-304.

Woodward-Lundgren and Associates, 1974, Supplementary geologic investigation, Rancho San Jose, California: Unpublished consultant's report, March 20, 1974.

Youd, T.L., 1971, Landsliding in the vicinity of the Van Norman Lakes in the San Fernando, California, earthquake of February 9, 1971: U.S. Geological Survey Professional Paper 733, p. 105-109.

Youd, T.L., 1973a, Liquefaction potential of unconsolidated sediments in the southern San Francisco Bay region, California: U.S. Geological Survey open file report.

Youd, T.L., 1973b, Liquefaction, flow, and associated ground failure: U.S. Geological Survey Circular 688, 12 p.

Ziony, J.I., *et al.*, 1973, Recency of faulting; a widely applicable criterion for assessing the activity of faults: Proceedings of fifth world conference on earthquake engineering, Rome, Italy, June 1973.

*Indicates references pertaining to landslides.

APPENDIX A
Personnel and Investigations

ACKNOWLEDGMENTS

Many persons and organizations contributed valuable data and consultation to this study. Organizations and persons who provided contributions include:

California Division of Mines and Geology: Charles C. Bishop (compilation and evaluation of subsurface geologic data); Rodger H. Chapman, Duane A. McClure (compilation and evaluation of subsurface geologic data and geophysical studies); Roger W. Sherburne (seismicity); Edward E. Welday (tsunami and seiche analysis); Josephine M. Territo, Marilyn Dayton, Marianne K. Roja, Betty Van Den Berg (clerical); Richard R. Moar, Vivian W. Muston, Donald R. Anderson, Richard T. Boylan, Edward L. Foster (drafting); Charles C. Bishop, Richard M. Stewart, Roger W. Sherburne, Thomas E. Gay, Jr., Carl J. Hauge, James E. Slosson, Trinda B. Ristau (review).

U. S. Geological Survey: Earl E. Brabb (geologic map compilation, slope map); Perry R. Wood, David A. Webster (ground water and subsurface geologic data); Kenneth R. Lajoie, Edward J. Helley (Pleistocene-Holocene history of San Francisco Bay); Donald R. Nichols, Robert M. Hazelwood, William B. Joiner (subsurface geophysical parameters); Robert H. Wright (landslide analysis).

California Department of Water Resources: Robert S. Ford (ground water and subsurface geologic data).

California Department of Transportation: Adlai F. Goldschmidt, Harold E. Beeston, Milton E. Heanney, W. Todd Nelson, Richard C. Wilhelms (subsurface geologic data).

Santa Clara Valley Water District: Thomas I. Iwamura, Frank W. Fenzel (landslide, ground water, and subsurface geologic data).

San Jose Water Works: Robert M. Ritchey (subsurface data--Santa Clara Valley).

Cooper-Clark & Associates: Michael F. Eagen, Gary B. Taggart (data from City of San Jose Seismic Safety Study).

Applied Soil Mechanics: Ben A. Patterson, William Zehrbach (subsurface data and cores from San Francisco Bay).

W. A. Wahler & Associates: Leonardo Alvarez (Hayes Valley dam site study).

Burkland & Associates: Jean D. Smith, Murray Levish (subsurface data in Milpitas area).

Dames & Moore: Bruce C. Auld and A. Allen Weymouth (subsurface data in Mountain View area).

Palo Alto Building Department: Stan J. Nowicki (site soil studies).

Morgan Hill Public Works Department: James M. Higgins (water well data).

Gilroy Public Works Department: Richard L. Cox (water well data).

In addition, the authors gratefully acknowledge helpful discussions with William R. Cotton and Robert L. Rose.

The manuscript was reviewed by Professor H. Bolton Seed (University of California at Berkeley), Frank E. McClure (McClure and Messinger), James O. Berkland (Santa Clara County Department of Public Works), and Eleanor J. Young (Santa Clara County Planning Department).

TYPES OF INVESTIGATIONS

Compilation, evaluation, and interpretation of existing data constituted the principal effort of this study. Field work was undertaken to check data locally and to obtain regional perspectives that assisted in interpretations. Both ground inspection and air photo interpretation of landslides and of various geologic units were conducted throughout the county.

Seismic data from the University of California at Berkeley, the California Institute of Technology, and the U. S. Geological Survey--which are being incorporated into the California Division of Mines and Geology earthquake catalog--were used. These data are plotted in plate 2.

APPENDIX B
Data: Sources, Method of Presentation, and Limitations

SOURCES

Areal geologic mapping (see plate 1, Geologic map) was obtained from a recent (in progress) U. S. Geological Survey compilation and was modified locally by the California Division of Mines and Geology. Subsurface geologic and hydrologic data were obtained from many sources (see Appendix A--Acknowledgments) and are shown on plates 3, 4, and 5.

See Acknowledgments and Appendix D for specific references to the above data.

METHOD OF PRESENTATION

The basic data are presented on plates 1, 2, 3, 4, and 5 and are discussed in the text. Interpretations and recommendations are presented in the text and graphically on plate 6. The three map units shown on plate 6 were suggested by the Santa Clara County Planning Department.

The California Division of Mines and Geology interpreted the basic data and constructed the map.

LIMITATIONS

Nonuniform Reliability of Geologic Data

The geologic map of Santa Clara County (plate 1) is a compilation of geologic maps of various scales made for various purposes. In addition, factors such as heavy vegetative cover in the Santa Cruz Mountains limit reliability. Assuming that, in general, more detailed data are more reliable, a reliability index map is shown in Appendix C. A source index map and list of references are shown in Appendix D.

Special Problems with Subsurface Data

Subsurface information was collected from a number of sources such as the California Department of Water Resources (well logs of water wells drilled in Santa Clara County during this century), the California Department of Transportation Bridge Section (engineering borings for overpass and bridge construction generally between 1950 and present), private consultants (foundation studies for office structures and subdivision investigations), and the U. S. Geological Survey (investigation for ground subsidence and earthquake monitoring stations). For a more complete listing of the data sources, see Acknowledgments.

Even though a large quantity of data were available, a number of deficiencies have been noted. Particular problems developed with the water well information. Because of the large number of private water-well drilling organizations involved, there are wide variations in the manner of the data presentation and the quality of the data. As a general rule, the lithologic descriptions given on the logs are very generalized, sometimes questionable, and can only infrequently be used for correlations between well sites. On a number of logs, it was noted that the location of the well was in error, sometimes as much as several miles. The level of the water given on some of the water-well logs was ambiguous. It was difficult to determine if the level recorded was the position of the first water encountered or the stabilized water level after the well had been completed. Data identified as erroneous or uncertain were not used in this report.

Water-level data, whether from water-well logs or from engineering borings, were collected at different times during the year, thus raising the problem of natural variation throughout the year, from wet to dry season. At present, there is no adequate solution to these problems, but the effect of the variation in the data can be reduced by collecting as many data as possible and thus minimizing the smaller local variations.

The data obtained from the Department of Transportation and from private consultants proved to be much more useful; for example, locations were accurate, and lithologic descriptions were given in detail. The major shortcoming of these data was the shallowness of the borings, only a few of which were deeper than 100 feet.

Inadequacy of Historic Earthquake Record in California (1769-present)

The historic earthquake record is less than adequate because: 1) it represents too short a period to provide a statistically adequate number of earthquakes with long recurrence intervals (greater than 100 years), and 2) the increase in population since 1769 has produced an apparent increase in the number of earthquakes because small events that earlier escaped notice are being recorded. In addition, the increase in number and quality of seismographs has permitted the more accurate location of earthquake epicenters.

Youthful "State of the Earthquake Art"

The "state of the art" in the earthquake sciences is rapidly evolving. As interpretation of new data, derived from future earthquake investigations and future earthquake research, advances the "state of the art", reinterpretation of the earlier data will be necessary.

APPENDIX C
Detail and Reliability of Geologic Data

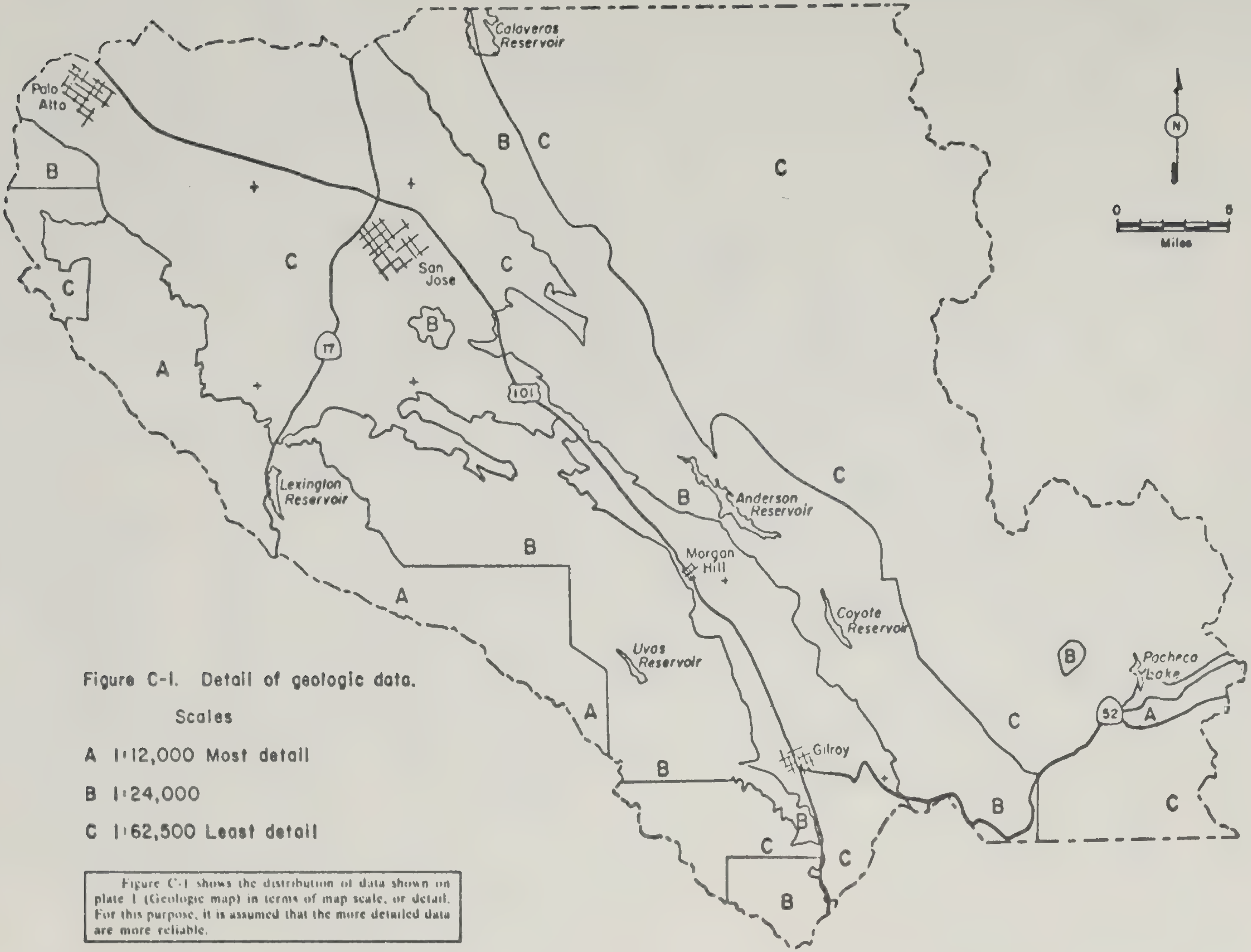


Figure C-1. Detail of geologic data.

Scales

A 1:12,000 Most detail

B 1:24,000

C 1:62,500 Least detail

Figure C-1 shows the distribution of data shown on plate 1 (Geologic map) in terms of map scale, or detail. For this purpose, it is assumed that the more detailed data are more reliable.

APPENDIX D
Index Map and References: Geologic Data

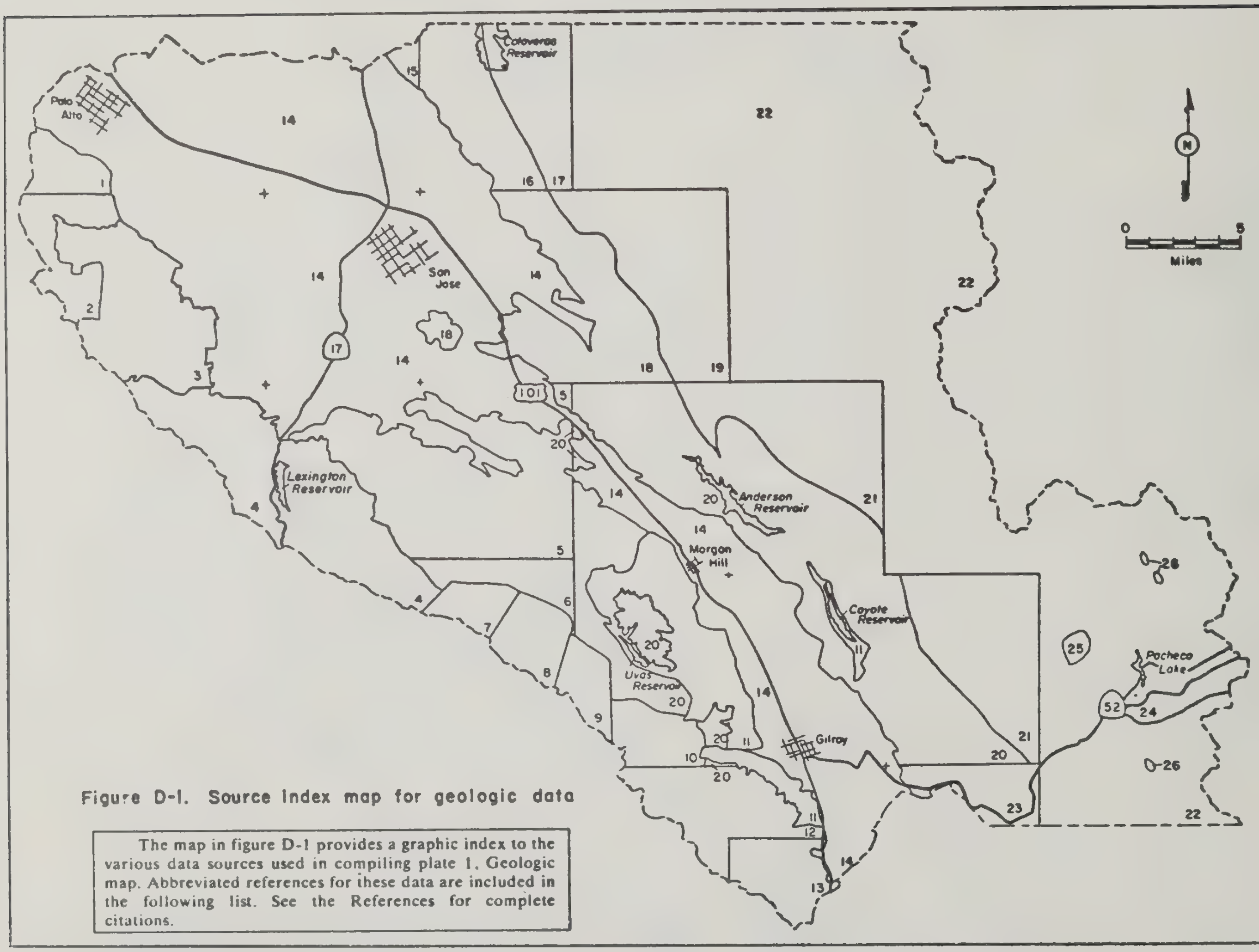


Figure D-1. Source index map for geologic data

The map in figure D-1 provides a graphic index to the various data sources used in compiling plate 1, Geologic map. Abbreviated references for these data are included in the following list. See the References for complete citations.

Map reference number	Abbreviated reference	Map reference number	Abbreviated reference
1	Pampeyan, 1970.	15	Dibblee, 1972b; Crittenden, 1951.
2	Dibblee, 1966.	16	Dibblee, 1973b; Crittenden, 1951.
3	Rogers and Armstrong, 1973.	17	Cotton, 1972; Dibblee, 1973b; Crittenden, 1951.
4	Rogers, 1972 (local modifications, 1974).	18	Dibblee, 1972a; Dibblee, 1972c; Fugro, Inc., 1973.
5	Bailey and Everhart, 1964 (generalized by E. E. Brabb and slightly modified east of Calero Reservoir by CDMG).	19	Cotton, 1972; Dibblee, 1972a; Dibblee, 1972c.
6	McLaughlin, 1971b.	20	Dibblee, 1973a (for additional paleontologic data in Diablo Range, see Bennett, 1972; Carter, 1970; Bartsch, in preparation); local additions along Coyote Creek fault zone from Woodward-Lundgren and Associates, 1974).
7	Simoni, in preparation; McLaughlin, 1971b.		
8	Osbun, in preparation; McLaughlin, 1971b.		
9	Bauer, 1971; McLaughlin, 1971b.		
10	McLaughlin, 1971a; McLaughlin, 1971b.	21	Cotton, 1972; Dibblee, 1973a.
11	Williams *et al.*, 1973.	22	Cotton, 1972; Wahler & Associates, 1970.
12	Allen, 1946 (extensively modified by T. W. Dibblee, Jr., and E. E. Brabb).	23	Hall, 1974; Rogers, in progress; Dibblee, unpublished data.
13	Bishop, in progress.		
14	Helley and Brabb, 1971; California Department of Water Resources, in press; California Department of Water Resources, 1967.	24	Klein, 1962.
		25	McKee, 1965.
		26	Berkland, unpublished data.

APPENDIX E
Geologic Time

	RELATIVE GEOLOGIC TIME				ATOMIC TIME millions of years before present	TIME OF APPEARANCE OF DIFFERENT FORMS OF LIFE
	Era	Period		Epoch		
Age of Mammals	Cenozoic	Quaternary		Holocene	0.011*	
				Pleistocene	2-3	Ice age, evolution of man.
		Tertiary		Pliocene	5-7**	Age of mammoths.
				Miocene	23-26**	Spread of anthropoid apes.
				Oligocene	37-38	Origin of more modern families of mammals, grazing animals.
				Eocene	53-54	Origin of many modern families of mammals, giant mammals.
				Paleocene	65	Origin of most orders of mammals, early horses.
Age of Reptiles	Mesozoic	Cretaceous		Late Early	136	Appearance of flowering plants; extinction of dinosaurs at end; appearance of a few modern orders and families of mammals.
		Jurassic		Late Middle Early	190-195	Appearance of some modern genera of conifers; origin of mammals and birds; height of dinosaur evolution.
		Triassic		Late Middle Early	225	Dominance of mammal-like reptiles.
	Paleozoic	Permian		Late Early	280	Appearance of modern insect orders.
		Carboniferous Systems	Pennsylvanian	Late Middle Early		Dominance of amphibians and of primitive tropical forests which formed coal; earliest reptiles.
			Mississippian	Late Early	345	Earliest amphibians.
		Devonian		Late Middle Early	395	Earliest seed plants; rise of bony fishes.
		Silurian		Late Middle Early	430-440	Earliest land plants.
		Ordovician		Late Middle Early	500	Earliest known vertebrates.
		Cambrian		Late Middle Early		Appearance of most phyla of invertebrates.
	Precambrian					Origin of life; algae, worm burrows.

Modified from G. Ledyard Stebbins, *Processes of organic evolution*, 1966. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

*11 000 years. Ziony *et al.* (1973).

**Geological Society of London (1964). Berggren (1972).

APPENDIX F

Earthquake Scales

MODIFIED MERCALLI INTENSITY SCALE OF 1931[1] (1956 version[2])

Masonry A, B, C, D. To avoid ambiguity of language, the quality of masonry, brick or otherwise, is specified by the following lettering.

Masonry A. Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

I.	Not felt. Marginal and long-period effects of large earthquakes.
II.	Felt by persons at rest, on upper floors, or favorably placed.
III.	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV.	Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.
V.	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI.	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken visibly, or heard to rustle.
VII.	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices also unbraced parapets and architectural ornaments. Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII.	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX.	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.
X.	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI.	Rails bent greatly. Underground pipelines completely out of service.
XII.	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

[1] Original 1931 version in Wood, H. O., and Neumann, F., 1931, Modified Mercalli intensity scale of 1931: *Seismological Society of America Bulletin*, v. 53, no. 5, p. 979-987.

[2] 1956 version prepared by Charles F. Richter, *in Elementary Seismology*, 1958, p. 137-138, W. H. Freeman & Co.

RICHTER MAGNITUDE SCALE

The Richter magnitude scale is a measure of the energy radiated from an earthquake. The theoretical energy difference between any two whole numbers on the Richter scale is not "1", as on a ruler, but rather is approximately "30". Therefore, a magnitude 3.0 earthquake equals 30 times the energy of a magnitude 2.0 earthquake (Hill, 1969; Bolt, 1970).

The implications of this "30" factor can be visualized in various ways. In table F-1 (compiled from Hill, 1969; Richter, 1958; Hadley, 1970; Tocher, 1970; Willis *et al.*, 1972), Richter magnitude is equated with A) the theoretical earthquake energy radiated beyond the focus (usually expressed in *"ergs")* as pounds or tons of TNT, and B) energies of nuclear explosions that have produced earthquakes of certain magnitudes.

It can be seen by inspection of this table that the energy difference between 7.0 and 8.0 magnitudes is vastly greater than the energy difference between 2.0 and 3.0 magnitudes. Also, it is apparent that for an earthquake of a given magnitude, the total energy of the nuclear explosion which produced that earthquake is far greater than the theoretical seismic energy represented by that earthquake. Apparently, only a part of the nuclear explosion energy is transformed into earthquake energy -- much of the nuclear energy being transformed into heat, light, etc. that crushes and melts the rock near the explosion point (Tocher, 1970; Bolt, 1970).

Another visual method for portraying the relative sizes of Richter magnitudes is shown in figure F-1. The volumes of the spheres shown in circular cross section are roughly proportional to the amount of energy released by earthquakes of Richter magnitudes 1, 2, and 3. At the same scale, the sphere representing the San Francisco 1906 earthquake (magnitude 8.3) would have a radius of 110 feet (33.6 meters).

RELATIONSHIP BETWEEN EARTHQUAKE MAGNITUDE AND ENERGY

The volumes of the spheres are roughly proportional to the amount of energy released by earthquakes of the magnitudes given, and illustrate the exponential relationship between magnitude and energy. At the same scale the energy released by the San Francisco earthquake of 1906 (Richter magnitude 8.3) would be represented by a sphere with a *radius* of 110 feet.

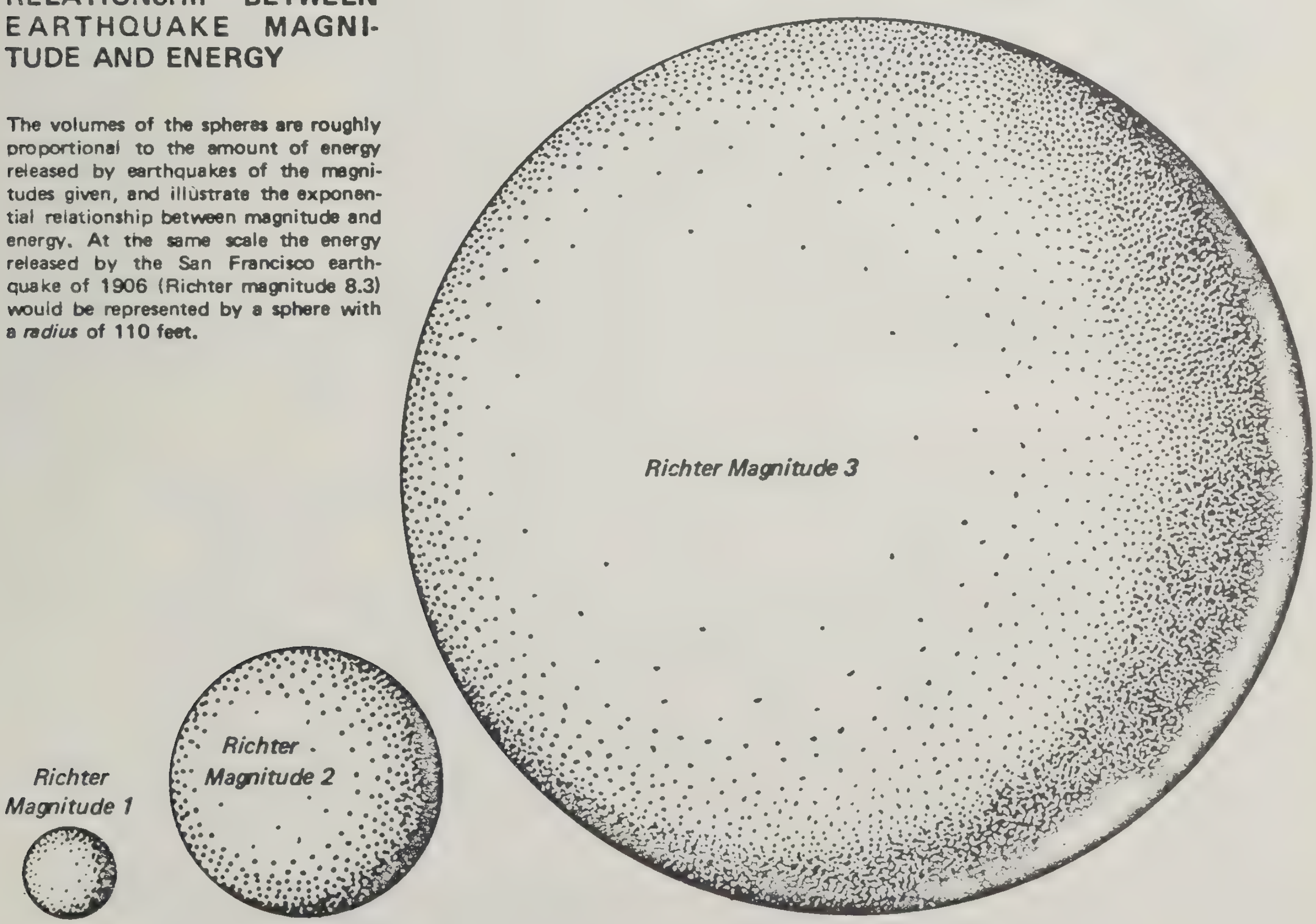


Figure F-1. Relative size of Richter magnitudes.

Table F-1. Richter magnitude and energy.

		Richter magnitude scale	Energies of certain nuclear explosions (tons of TNT)	Approximate theoretical earthquake energies** (equivalent units of TNT)
		1.0		6 oz.
		1.5		
		2.0		13 lbs.
		2.35	"Mad" (430 tons)	
		2.5		
Minor*	E*	3.0		397 lbs.
		3.5		
		4.0		6 tons
		4.5		
		5.0		199 tons
		5.3		
	D*	5.5		
		5.6	"Bilby" (200,000 tons), Nevada	
Moderate*		5.9		
		6.0		6,270 tons
	C*	6.1-6.3	"Benham" (1,100,000 tons) and "Boxcar" (1,200,000 tons), Nevada	
		6.5		
		6.9		
Major*	B*	7.0	"Cannikin" (5,000,000 tons), Amchitka Island, Alaska	199,000 tons
		7.5		
		7.7		
		8.0		6,270,000 tons
Great*	A*	8.5		
		9.0		199,000,000 tons

*After Gutenberg and Richter (1949).
**Energy that is radiated beyond hypocenter and transmitted to, and recorded by, seismograph.

APPENDIX G

General Comparison of Richter Magnitude and Modified Mercalli Intensity at the Earthquake Epicenter

Magnitude and intensity of an earthquake are entirely different measurements of earthquake effects and can be compared only at the earthquake epicenter.

Magnitude is a number derived from instrumental measurements and is a measure of the energy radiated by the earthquake. While there are several methods of calculating magnitude, each method provides only one magnitude for each earthquake.

Intensity is a rating of earthquake effects as observed and reported by people at any given location. Intensity ratings for earthquakes vary from I to XII depending on distance from epicenter, the nature of the soil and rock beneath the observer, the observer's interpretation of events seen or felt, the focal mechanism, and the magnitude of the event.

The table below shows equivalent values of magnitude and intensity. For explanation of the various intensities, see the Modified Mercalli intensity scale of 1931 (1956 version).

Richter magnitude	Modified Mercalli intensity at the epicenter
2	I-III
3	III
4	IV-V
5	VI-VII
6	VII-VIII
7	IX-X
8	X-XII

After Richter (1958).

APPENDIX H

Classification of Landslides

Landslides are generally divided into four categories on the basis of the type of landslide movement: falls, slides, flows, and complex landslides (combinations of falls, slides and flows). Subdivisions of these categories are based on the type of material involved (falls), presence or absence of a dominant planar geologic structure (slides), and amount of water saturation (flows).

Table H-1. Definition of landslide types.

Type		Definition	Characteristics
FALLS	Rockfalls Soil falls Coastline falls	Free falls of soil and rock, local rolling, bouncing, or sliding.	Occurs chiefly on steep slopes. Rockfalls commonly result from loosening or undermining of outcrops of resistant rocks.
SLIDES	Planar slides (block glides) Rotational slides	Lateral and downslope movement of partly intact masses due to: A) failure along downsloping planar geologic structure (planar slide), or B) failure and rotation along curved slip surface.	Planar slides common in bedded Cenozoic-Mesozoic rocks. Rotational slides common in thick surficial deposits and massive Cenozoic and Mesozoic rocks.
FLOWS	Slow flows Fast flows Underwater flows	Viscous flows of completely fragmented material, saturated with water.	Move downslope in channels as tongues of mud and debris; similar to stream flow. Some begin as slides. Velocity depends on water content, type of debris, and slope angle.
COMPLEX	Combination of falls, slides, and flows	Combinations of the above.	Falls may occur from the steep scarp of a slide. Slides may disintegrate downslope into a flow.

This type of basic classification was originally proposed by Varnes (1958); and the above slightly modified version was adapted from Morton and Streitz (1967) and Leighton (1966).

The following list shows selected documented examples of these landslide types (from Morton and Streitz, 1967). All types except underwater flows and soil falls have been found in California.

A more complete landslide reference list can be found in Morton and Streitz (1967).

Table H-2. Examples of landslide types.

Landslide type and location of example	References
ROCKFALL (mode at time of initial movement)	
Elm, Switzerland	Buss and Heim, 1881; Heim, 1882
Mount Rainier, Washington U.S.A.	Crandell and Fahnestock, 1965
Blackhawk Canyon, San Bernardino County, California U.S.A.	Woodford and Harriss, 1928; Shreve, 1968
SOIL FALL	
New Madrid area, Missouri U.S.A.	Fuller, 1912
Amazon River, Brazil	Bates, 1875
COASTLINE FALL	
Norway	Brigham, 1906
Northern California coast U.S.A.	Lawson, chairman, 1908
PLANAR SLIDE	
Vaiont Dam, Italy	Selli *et al.*, 1964
Gros Ventre, Wyoming U.S.A.	Alden, 1928
Hebgen Lake, Montana U.S.A.	Hadley, 1964
Kettle Falls, Washington U.S.A.	Varnes, 1958
Point Fermin, California U.S.A.	Miller, 1931
ROTATIONAL SLIDE	
Echo Cliffs and Vermillion Cliffs, Arizona U.S.A.	Strahler, 1940
Orinda, California U.S.A.	Herling and Stafford, 1952
Pacific Palisades, California U.S.A.	McGill, 1959
Portuguese Bend, California U.S.A.	Merriam, 1960; Jahns and Vonder Linden, 1973
Cape Fortunas, California U.S.A.	Lawson, chairman, 1908
SLOW FLOW	
Horseshoe Bend, Idaho U.S.A.	Peebles, 1962
Grand Coulee Dam, Washington U.S.A.	Legget, 1962
Lassen Volcanic Park, California U.S.A.	Sharpe, 1938
Gilroy, California U.S.A.	Krauskopf *et al.*, 1939
San Clemente, California U.S.A.	Blanc and Cleveland, 1968
FAST FLOW	
Stillwater Range, Nevada U.S.A.	Blackwelder, 1928
Montrose, California U.S.A.	Troxell and Peterson, 1937
Wrightwood, California U.S.A.	Sharp and Nobles, 1953
UNDERWATER FLOW	
Zug, Switzerland	Heim *et al.*, 1888
Atlantic Ocean	Heezen and Ewing, 1952
Hawaiian Ridge, Pacific Ocean	Moore, 1964

APPENDIX I

Factors and Processes Affecting Landslide Potential

The following three tables describe the various natural factors and processes and various human factors which affect landslide potential. In the case of human factors, corrective measures that will minimize human impact are also listed.

These data were adapted from Leighton (1966) and Rogers and Armstrong (1973).

Table I-1. Natural factors affecting landslide potential.

Natural factor	Description
Weak rock or soil	Weakness may be due to: A) significant concentration of expansive clays; B) preponderance of poorly consolidated or unconsolidated material; C) preponderance of fine-grained materials; D) local shearing along faults; E) widespread shearing throughout units.
Orientation of geologic structure	Downslope inclination of zones or planes of weakness increase landslide potential. Planes of weakness include: A) bedding planes between strong and weak rock layers or bedding plane within weak rock units; B) joints in rock units; C) plunge of axial plane of folded rocks.
High water content	High water content can increase landslide potential and may be due to: A) retention of water preferentially in fine-grained material and on north-facing, sun-shaded slopes; B) period of intense local rainfall during period of high seasonal rainfall.
High slope angle and high relief	Steep slopes and high relief (elevation difference between ridges and valleys) in mountainous terrain may increase landslide potential when combined with weak bedrock or surficial units; for example, a stream eroding downward rapidly into weak units, producing locally steep, unstable slopes.

Table I-2. Natural processes affecting landslide potential.

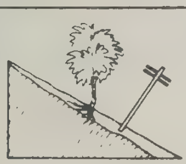
Schematic illustration	Definition of process	Characteristics
	SOIL CREEP Lateral and downslope movement of soil mantle at a slow rate in response to gravity.	No definite slip surface; essentially continuous movement in clay-rich soil, periodic movement in talus material.
	BEDROCK CREEP Plastic deformation (lateral and downslope) and fracturing of bedrock at a slow rate beneath the soil zone--in response to gravity.	No definite slip surface; produces open-structured materials; downslope bending of bedrock common; forms slowly.
	SUBSIDENCE-SETTLEMENT Movement is essentially vertical downward in response to gravity; may produce uneven (differential) settling of ground surface.	Occurs in organic, heterogeneous, open-structured deposits; compaction may result from oxidation of organic-rich deposits, such as peat, or slow decay of intermixed vegetation in landslide debris.

Table I-3. Human factors affecting landslide potential.

Causes and effects	Corrective measures to minimize increase in landslide potential
GRADING	
Grading can increase landslide potential by: steepening of slopes; removal of downslope support during excavation; addition of weight upslope during filling; utilizing improperly compacted fills; utilizing fills containing compressible clay-rich material or organic debris.	Design for minimal grading. Cut slopes at 1.5-1 or less. Construct compacted fills using proper nonorganic materials. Use buttress fills or keyed fills to provide downslope support if necessary.
LOADING (addition of weight to slope)	
Loading of slope by construction of buildings, roads, swimming pools, etc., can increase landslide potential by exceeding bearing strength of soil and underlying material--especially if underlying material is porous and compressible (peat, recent landslide debris, abandoned dump debris, or uncompacted fill containing vegetative debris).	Design buildings, etc., in accordance with soil and subsoil bearing strengths (taking into account strength-reducing effects of added water from septic tank effluent, garden watering, etc.).
REMOVAL OF VEGETATION	
Vegetation removal can increase landslide potential by: removing "anchoring effect" of root network in soil; exposing soil to direct impact of rainfall, resulting in increased erosion; locally increasing water saturation in soil (adding water that would have been transpired by the removed vegetation).	Minimize vegetation removal. Plant ground cover on naturally bare or cut slopes; under severe conditions, hold planting in place with straw mulch, wire net, jute mesh, or plastic. Replace vegetation of low transpiration rate (grass) with plants of high transpiration rate (trees).
WATER	
Addition or redistribution and concentration of water can increase landslide potential locally. Sources of additional water include septic tank effluent, garden watering, and leakage from swimming pools. Redistribution of water results from altering natural drainage and from construction of large impermeable surfaces (roofs, patios, paved surfaces) that divert and concentrate rainfall runoff and locally accelerate erosion.	Minimize "water-adding activities"; locate septic tank leach field, etc., away from edge of steep slope. Include natural drainage in design. Divert surface runoff away from head and face of cut slopes if possible. Minimize construction of large impermeable surfaces; direct runoff from such surfaces into natural drainage. Plant high-transpiration vegetation on cut slopes and cleared areas.

References*

Borcherdt, R. D. (1970) "Effects of Local Geology on Ground Motion Near San Francisco Bay," Bulletin of the Seismological Society of America, Vol. 60, No. 1, February.

Gutenberg, B. (1957) "The Effects of Ground on Earthquake Motion," Bulletin of the Seismological Society of America, Vol. 47, No. 3, July, pp. 221-251.

Kanai, K, Tanaka, T. and Osada, K. (1954) "Measurement of the Micro-Tremor, I," Bulletin of the Earthquake Research Institute, Vol. 32, Part 2, July, pp. 199-209.

Kanai, K., Tanaka, T. and Yoshizawa, S. (1959) "Comparative Studies of Earthquake Motions on the Ground and Underground (Multiple Reflection Problem)," Bulletin of the Earthquake Research Institute, Vol. 37, Part 1, March, pp. 53-88.

MacMurdo, J. (1824) "Papers Relating to the Earthquake Which Occurred in India in 1819," Phil. Mag., Vol. 63, pp. 105-177. This article also appeared in the Royal Asiatic Society of London and Dublin, Bombay Branch, Vol. 3, pp. 90-116, 1823.

Ohashi, Yorihiko (1966) "Niigata Earthquakes, 1964 Building Damage and Soil Condition," Soil and Foundation, Vol. VI, No. 2, March, pp. 14-37.

Seed, H. Bolton and Alonso, G., Jose Luis (1974) "Efectos de Interaccion Suelo-Estructura en el Terremoto de Caracas de 1967," I Congreso Venezolano de Sismologia e Ingenieria Sismica, Caracas -1 Venezuela, October 1974.

Seed, H. Bolton and Wilson, Stanley D. (1967) "The Turnagain Heights Landslide, Anchorage, Alaska," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 93, No. SM4, Paper 5320, July, pp. 325-353.

Wiggins, John H. (1964) "Effect of Site Conditions on Earthquake Intensity," Journal of the Structural Division, ASCE, Vol. 90, No. ST2, April.

Wood, H. O. (1908) "Distribution of Apparent Intensity in San Francisco," in "The California Earthquake of April 18, 1906," Report of the State Earthquake Investigation Commission, Carnegie Institution of Washington, Washington, D.C., pp. 220-245.

*References for "Soil and Geologic Effects on Building Damage During Earthquakes" by H. Bolton Seed, Professor of Civil Engineering, U. C. Berkeley, CA.

References*

Borcherdt, R. D. (1970) "Effects of Local Geology on Ground Motion Near San Francisco Bay," Bulletin of the Seismological Society of America, Vol. 60, No. 1, February.

Gutenberg, B. (1957) "The Effects of Ground on Earthquake Motion," Bulletin of the Seismological Society of America, Vol. 47, No. 3, [illegible]

Kanai, K., Tanaka, T. and Osada, K. (1954) "Measurement of the Micro-Tremor, I," Bulletin of the Earthquake Research Institute, Vol. 32, Part 2, [illegible]

Kanai, K., Tanaka, T. and Yoshizawa, S. (1959) "Comparative Studies of Earthquake Motions on the Ground and Underground, (Multiple Reflection Problem)," Bulletin of the Earthquake Research Institute, Vol. 37, Part 1, March, pp. 53-87.

[illegible] (1925) [illegible] in 1924 [illegible] Vol. 33, pp. 186-172. [illegible] at the [illegible] Society of [illegible] pp. 155-156, 1925.

[illegible] (1953) "[illegible] Earthquakes, [illegible]," [illegible]

Seed, H. Bolton and Idriss, I. M. [illegible] (1967) "Analysis of [illegible] Liquefaction [illegible] Earthquake of [illegible]," [illegible]

Seed, H. Bolton and Wilson, Stanley D. (1967) "The Turnagain Heights Landslide, Anchorage, Alaska," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 93, No. SM4, Proc. Paper 5320, July, pp. 325-353.

[illegible] (1969) "[illegible] on the [illegible]," Journal of the [illegible], Vol. [illegible], pp. [illegible]

[illegible] "[illegible] of [illegible] Earthquake of April 18, 1906," Report of the State Earthquake Investigation Commission, Carnegie Institution of Washington, Washington, D.C., pp. 220-245.

*References for "Soil and Amplitude Effects on Building Damage During Earthquakes" by H. Bolton Seed, Professor of Civil Engineering, U. of California, Berkeley.

COUNTY OF SANTA CLARA
PLANNING DEPARTMENT
314 County Administration Building
70 West Hedding Street
San Jose, California 95110

RETURN POSTAGE GUARANTEED

BULK RATE
U.S. POSTAGE
PAID
San Jose, Calif.
Permit No. 1406

M5302
INST OF GOVT STUDIES LIBRARY
UNIV OF CALIF AT BERKELEY
BERKELEY CA 94720

Published by the County of Santa Clara Planning Department 70 West Hedding Street, San Jose, California 95110